THE BOEING COMPANY

AIRPLANE DIVISION P.O. BOX 707 RENTON, WASHINGTON 98058

CODE IDENT. NO. 81205

	NUMBER D6-1	19860					
	nasa cr	R-62037	•				
TITLE: 367-80 VARIABLE STABILITY SIMULATION SYSTEM							
		TRANSPORT SIM					
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MODEL	367-80	CONTRACT.	NAS2-3224				
ISSUE NO	1	ISSUED TO:	nasa	ames			
	Prepare	ed by: <u>Y. W.</u> G. N.,	Baska	1-25-66			
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ABSTRACT

Concerning the use of a large four-engine jet airplane, Boeing 367-80 (707 prototype) as an in-flight dynamic simulator for the simulation of other large transport type airplanes operating in the subsonic region, including the approach and landing phases of flight.

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INTRODUCTION

During 1965, the Airplane Division of The Boeing Company undertook a program, utilizing the Boeing 367-80 airplane (707 prototype), which would provide inflight dynamic simulation of large airplanes in their landing configurations. The bulk of the work was carried out under two separate MASA contracts. The first contract, MAS 1-4096, was for the simulation of large supersonic transport-type airplanes and the flight test program was conducted at the MASA Langley facility at Langley AFB, Virginia.

A description of the simulation system as used for the Langley program can be found in Boeing Document D6-19856, "367-80 Airplane Variable Stability Simulation System (MASA Langley Supersonic Transport Simulation Program)" (Ref. A), and the results of the program are detailed in Boeing Document D6-10743, "Simulation of Three Supersonic Transport Configurations with the Boeing 367-80 In-Flight Dynamic Simulation Airplane" (Ref. B).

The second contract, NAS 2-3224, was for the simulation of a very large subsonic transport-type airplane and the flight test work was performed at the NASA Ames Research Center at Moffett Field, California.

The objectives of this program were:

- a. To establish requirements for satisfactory roll control characteristics of large, heavy airplanes in the landing approach.
- b. To establish requirements for satisfactory and minimum acceptable longitudinal dynamic stability and control characteristics of large, heavy airplanes in the landing approach.

The subject document describes the simulation systems as used for the MASA Ames program and includes descriptions of the technique, hardware, operational procedures and the various configurations simulated.

The results of the NASA Ames Program are described in Boeing Document D6-15000 "Lauge Transport Landing Chapacteristics as Simulated in Flight and on the Ground" (Reference C).

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LIST OF SYMBOLS

V	Velocity
ø	Angle of Attack
\boldsymbol{eta}	Angle of Sideslip - Wind from Right of Nose
Ө	Pitch Angle - Nose Up
Q	Pitch Rate
ϕ	Roll Angle - Right Wing Down
Р	Roll Rate
Ψ	Yaw Angle - Nose Right
R	Yaw Pate
Δ	Flight Path Angle - Climb
δε	Simulated A.L.T. Elevator
ΔTA.L.T.	Simulatei A.L.T. Thrust
δw	Simulated A.L.T. Wheel
δr	Simulated A.L.T. Rudder
δec	-80 Elevator Command
Sthc	-80 Thrust Command
Sabc	-80 Spoiler Command
δως	-80 Wheel Command
8rc	-80 Rudder Command
CL	Lift Coefficient
Co	Drag Coefficient
Cm	Pitching Moment Coefficient - Nose Up
Ce	Rolling Moment Coefficient - Right Wing Down
Cn	Yawing Moment Coefficient - Nose Right
CY	Side Force Coefficient - To Right

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LIST OF SYMBOLS (Continued)

T Engine Thrust

M Airplane Mass

Ixx Roll Axis Inertia

Ivy Pitch Axis Inertia

Izz Yaw Axis Inertia

1.0 SUMMARY

1.1 BACKGROUND

The Boeing 367-80 airplane (707 prototype) was successfully modified to perform as an in-flight dynamic simulator for the simulation of very large transport airplanes in the approach and landing phases of flight.

Thirty five hours of flight time were completed while simulating a large transport airplane, referred to as the Ames Large Transport (A.L.T.) and various variations from this basic configuration.

When the test airplane was in the simulation mode, it was flown from the right hand seat by the "Evaluation Pilot."

The airplane performance was continuously monitored by the "Safety Pilot" in the left hand seat, who could take command at any time and revert to the normal 367-80 control systems by disengaging the simulation.

The Safety Pilot could also override the Evaluation Pilot's inputs with his own controls without disengaging the system.

1.2 CONFIGURATIONS TESTED

The basic configuration simulated was based on control and stability derivatives supplied by NASA Ames that were typical of a very large four-engine, subsonic jet transport airplane. The basic derivatives of this airplane, referred to as the Ames Large Transport (A.L.T.), are given in Appendix A, Sheet A30.

In addition, a number of variations were simulated which consisted of modified lateral directional and longitudinal axis characteristics.

The parameters modified were:

a. Interal-Directional Axis

Maximum Wheel Angle
Maximum Wheel Rate
Maximum Rolling Acceleration
Maximum Steady State Roll Rate
Roll Time Constant

b. Longitudinal Axis

Short Period Frequency
Short Period Damping
Elevator to Column Gearing
Elevator Control Power
Change of Lift Coefficient Due to Elevator

1.3 AIRCRAFT MODIFICATIONS

The modifications necessary to convert the 367-80 to a variable stability research airplane consisted of:

Conversion of the airplane to fully powered control surfaces by the addition of electro-hydraulic actuators. This gave the capability of moving the control surfaces by either a mechanical input from the Safety Pilot through the normal airplane control cable systems, or by an electrical command input when in the simulation mode. In addition, provision was made for modulating the positions of the spoiler panels and the thrust reverser clamshell doors with electrical commands.

The installation of a general purpose analog computer (Systron-Donner SD/80) which provided electrical command signals to the airplane control systems - elevators, ailerons, spoiler panels, rudder, and thrust reversers - to modify the response characteristics of the basic -80 airplane to conform to those of the A.L.T. configuration being simulated.

The installation of a special set of Evaluation Pilot's controls for the right hand seat position. These controls consisted of an instrumented column and wheel, a fake throttle lever and transducers on the existing rudder pedals, and provided electrical signals proportional to the Evaluation Pilot's control inputs. Electrical pitch and roll trim controls were also added.

The installation of special sensors and wiring for the measurement of such parameters as angle-of-attack, sideslip angle, pitch, roll and yaw rates, roll angle and airspeed. A 17-foot streamlined boom was added to the nose of the airplane to carry the & vane sensor. (See Fig. 1.)

The installation of a rack of special test equipment, referred to as the interface, which provided:

- a. Input and output connections to the computer.
- b. Isolation and demodulation, where necessary, for the signals from the various airplane sensors and proper scaling and biasing of the incoming and outgoing signals.
- c. Electronic control for the electro-hydraulic servo systems.
- d. Logic circuitry for the mode selection control allowing the simulation mode to be selected from either the cockpit or the interface station. This function also included error detection and display circuitry and provisions for automatic disengagement in the event of a malfunction.

1.4 TECHNIQUE OF SIMULATION

The technique adopted for the simulation system was essentially an open loop, low-gain compensation technique in which the response of the air-plane to any disturbance was modified by modulating the airplane control surface with electrical commands from the analog computer. Figure 15 shows a very simplified block diagram of the system.

The magnitudes of the electrical commands were obtained from the precalculated differences between the response of the basic 367-80 airplane and the response of the simulated A.L.T. to the same disturbance. They were based on the known stability and control derivatives of the 367-80 and the predicted derivatives of the simulated A.L.T.

The accuracy of the simulation depended primarily upon the accuracy with which the control and stability derivatives of the basic 367-80 were known. For this reason, the initial calculations for the gains used in the analog computer were followed up with flight tests for the purpose of "fine tuning" the simulation system to compensate for any discrepancy between the published values of the airplane derivatives and the true values under dynamic conditions.

This technique, unlike a high gain, closed loop feedback, or model following method, is not self-correcting and consequently has limitations regarding gross weight, e.g. location, etc., changes of which tend to affect the validity of the simulation.

Despite these drawbacks, the technique adopted was considered preferable to the model following method because of the high probability of structural bending modes coupling with a model system.

1.5 FACTORS AFFECTING THE ACCURACY OF THE SIMULATION

1.5.1 Linearization of the Equations of Motion

Because the computation system was based on linearized equations of motion for a rigid airframe, the validity of the simulation decreased as the airplane departed from the established trim condition. For this reason the following limits were established to keep the simulation within the desired accuracy:

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1.5.2 Knowledge of the Basic 367-80 Characteristics

The accuracy with which the basic 367-80 airplane could be simulated had a major effect on the overall simulation accuracy.

This factor became increasingly important if the airplane being simulated was radically different from the 367-80.

1.5.3 Accuracy of the Signals from Aircraft Sensors

The accuracy of the signals from the various aerodynamic sensors, i.e., angle-of-attack, sideslip angle, roll, yaw and pitch rates, roll angle and airspeed, was important since these signals fed directly into the computer to form the commands to the control surfaces.

1.5.4 Response Characteristics of the Control Surfaces

A further factor affecting the accuracy of the simulation was the response characteristics of the control surfaces. This included the frequency response of the servo systems plus any non-linearities in the linkage, and effects due to airloads.

1.5.5 Variations in Gross Weight and C.G. Location

Because the simulation was based on calculations assuming a 367-80 airplane of fixed gross weight and c.g. location any change in these two factors, due perhaps to fuel distribution before flight and consumption during flight, caused a deterioration in the simulation.

1.5.6 Atmospheric Conditions

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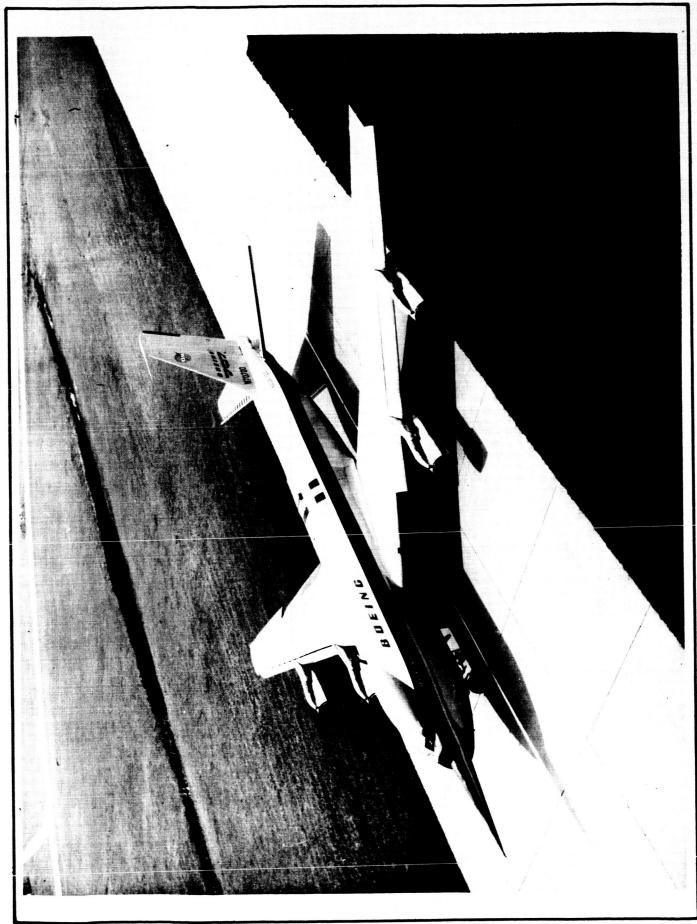
The above paragraphs refer to factors which were more or less under the control of the test engineer.

The 367.80 aerodynamic derivatives could be improved by means of increased flight time and increased knowledge of the basic -80 airplane characteristics.

The signals from the aircraft sensors could be improved with careful calibration and compensation.

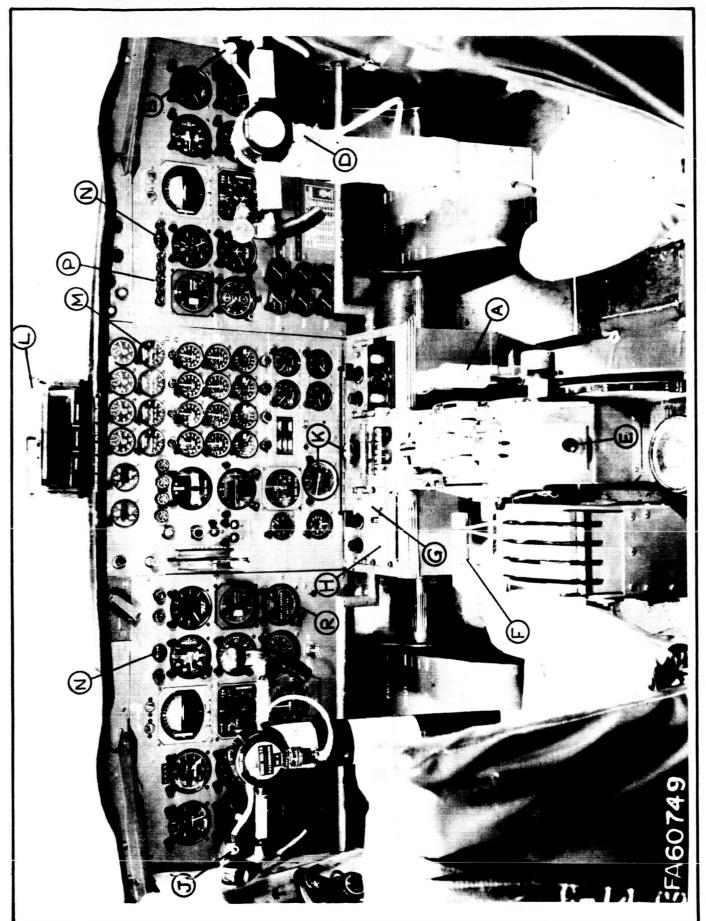
The discrepancies caused by using linear equations of motion could be calculated and limits set on the simulation to keep the accuracy within reasonable bounds. Similarly, the effects of change in gross weight and c.g. location could be calculated and allowed for.

However, the one factor which was out of the control of the test engineer was atmospheric turbulence. The major part of the problem with turbulence was caused by the production of erroneous angle-of-attack and sideslip angle readings due to local gusts at the $\alpha\beta$ vane. These signals were immediately fed into the computer resulting in commands to the control surfaces which caused erroneous motions of the airplane. For this reason the flight testing was restricted to conditions of zero to light turbulence.

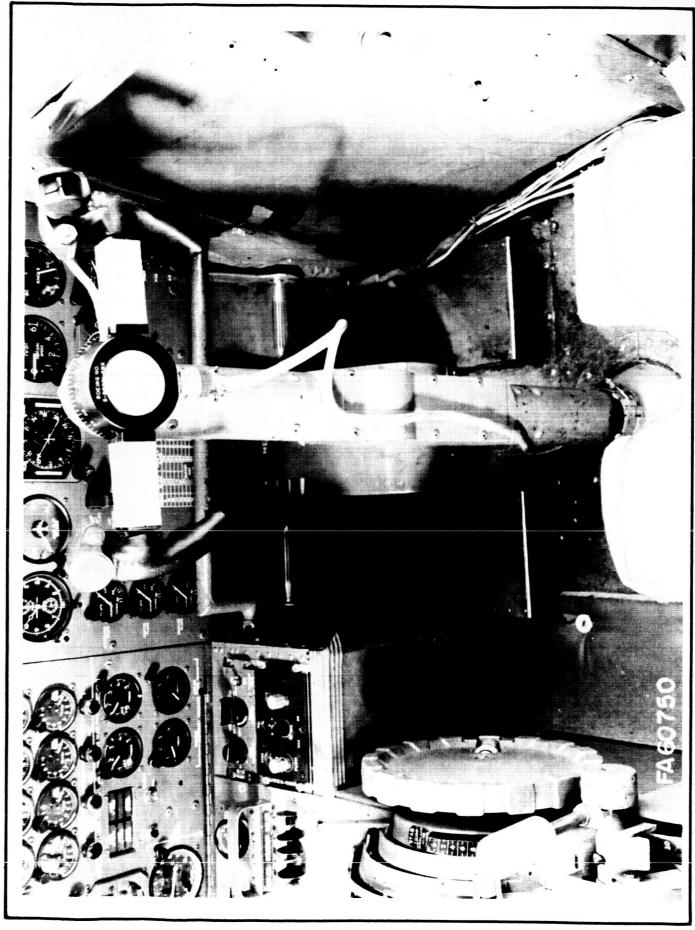


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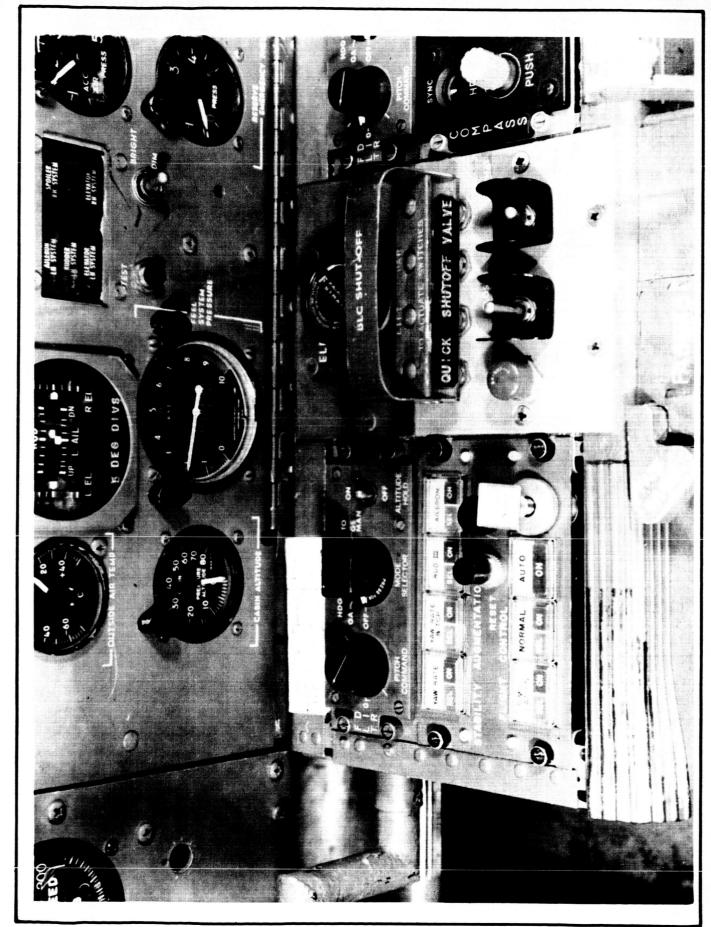


SHEET 13



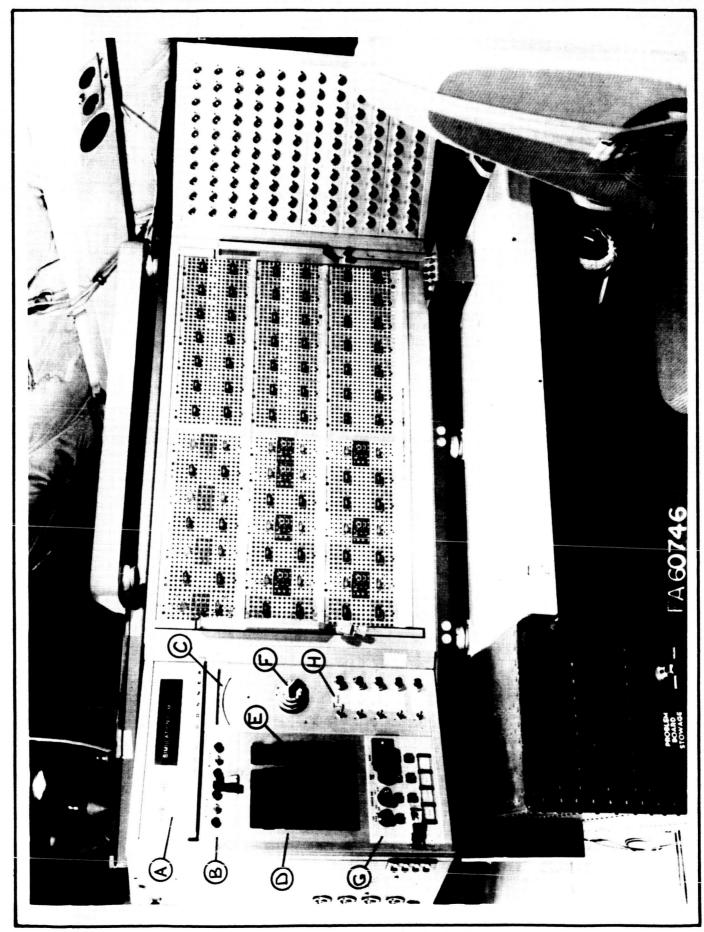
SHEET 14

FIG. 3



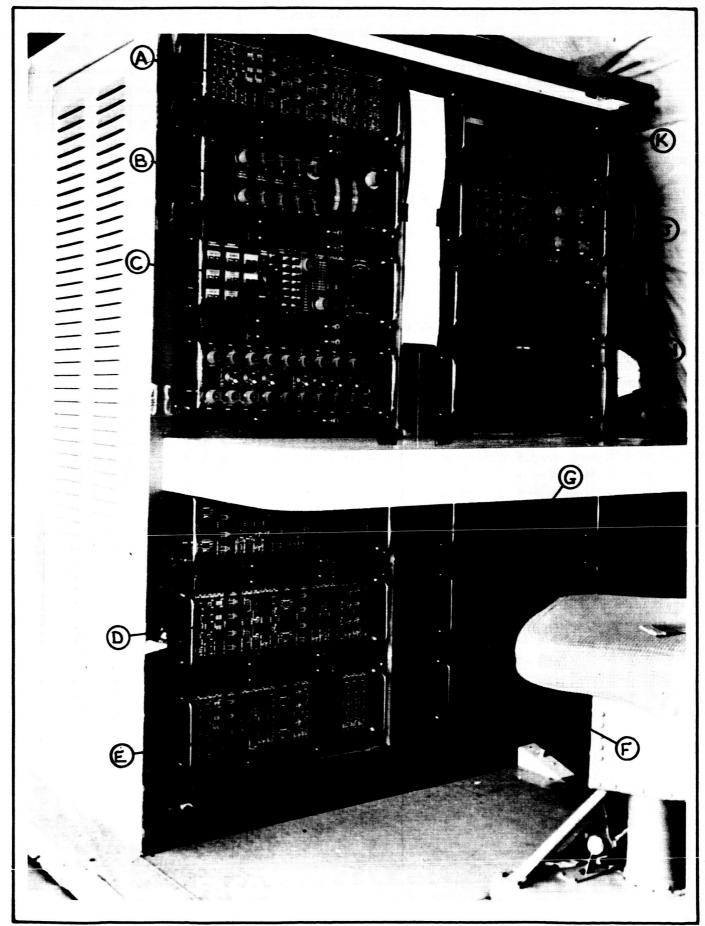
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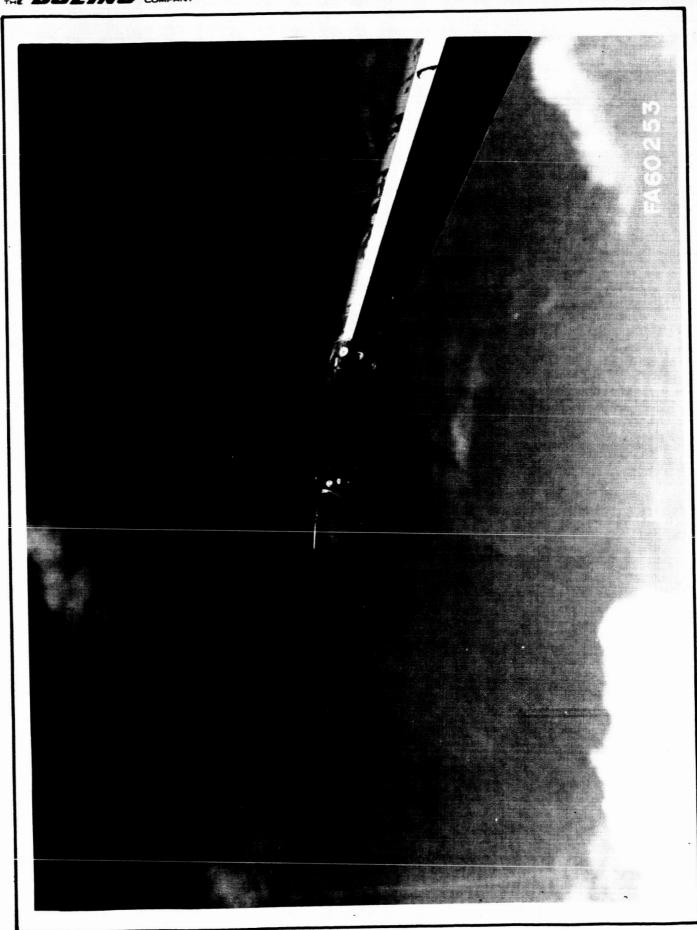
SHEET 16

FIG. 5



SHEET 17

FIG. 6



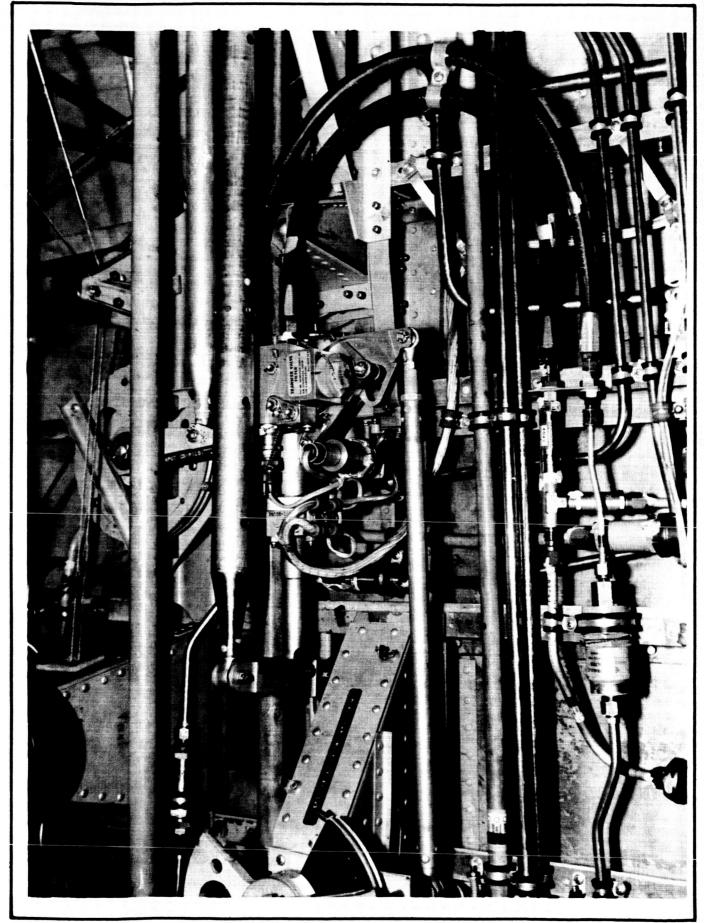
SHEET 18

FIG. 7

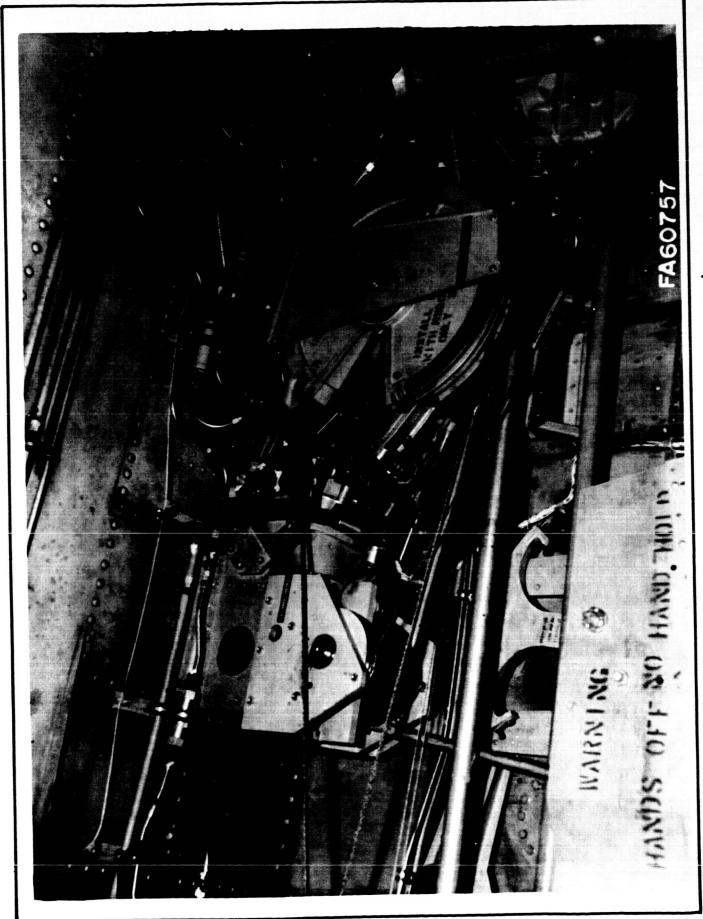


SHEET 19

FIG. 8

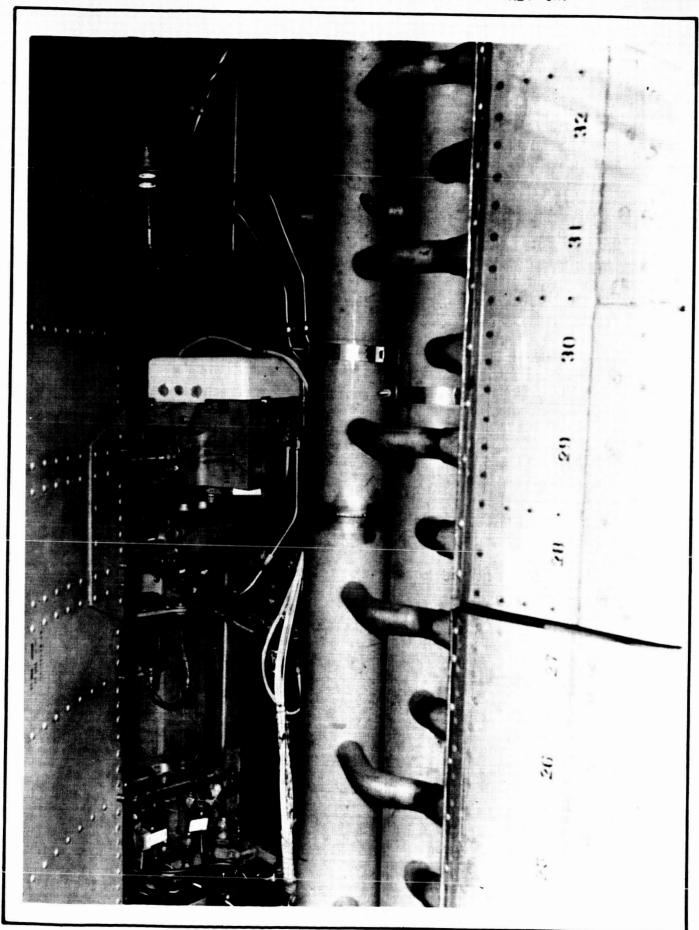


SHEET 20



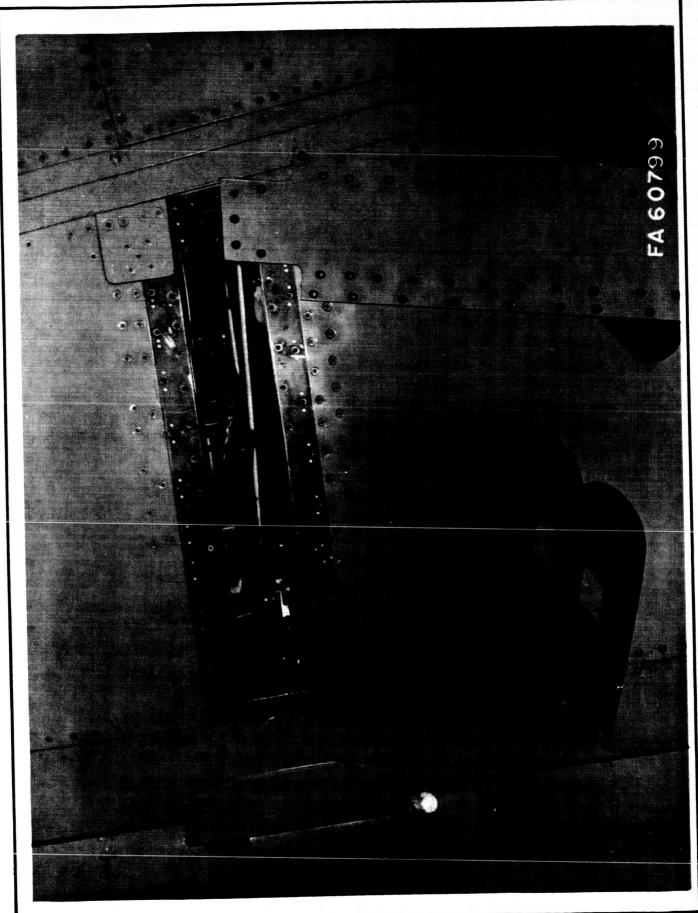
SHEET 21

FIG. 10

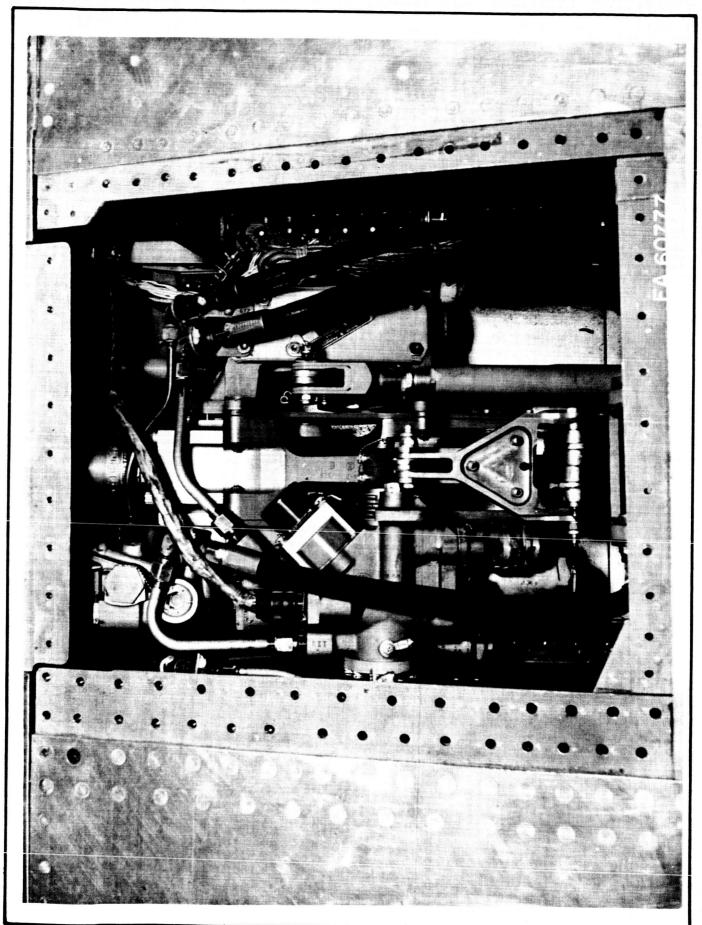


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FIG. 11



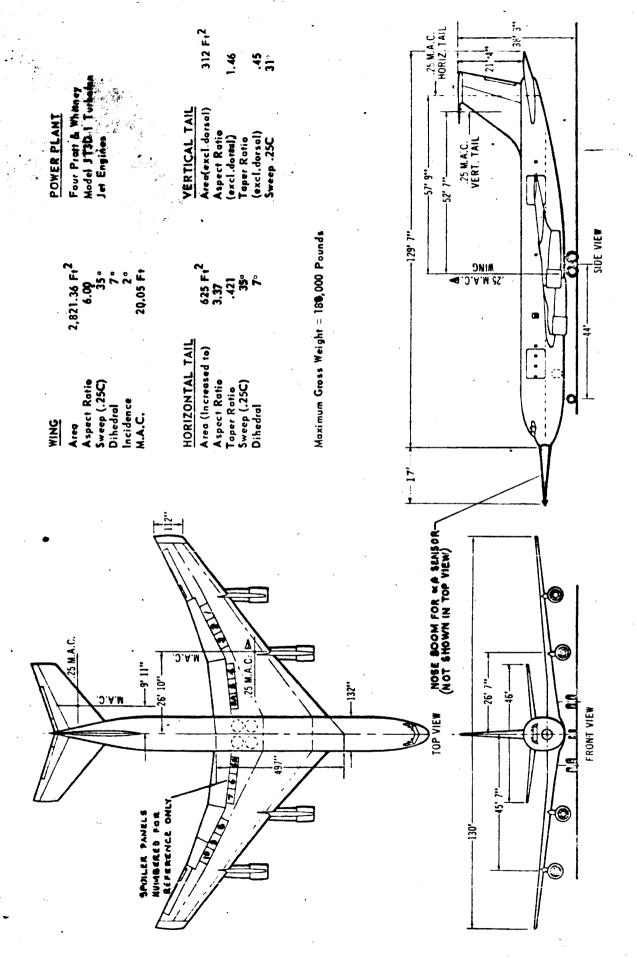
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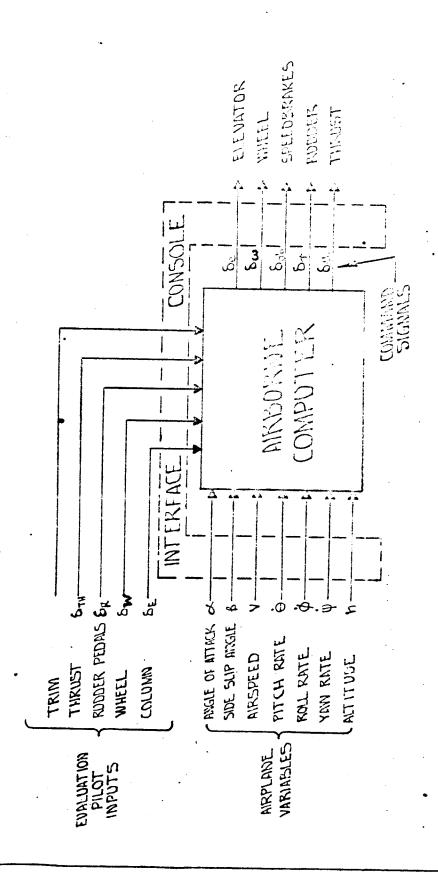




SHEET 24

MODEL 367-80 CHARACTERISTIC

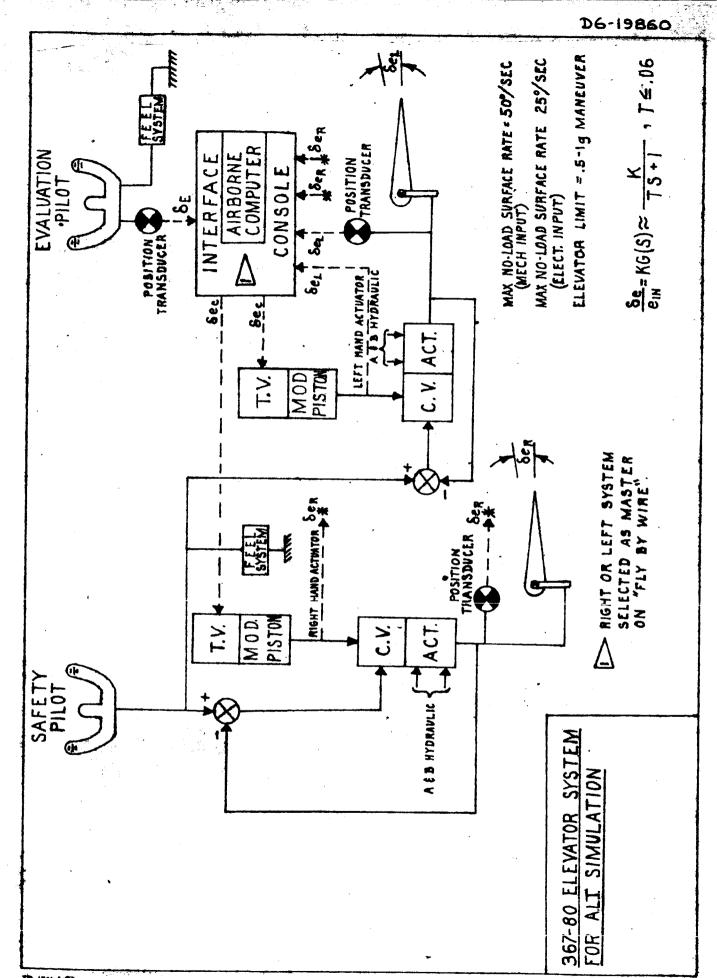




367-20 ALT SHINLLWICH AIRBORNE COMPUILE

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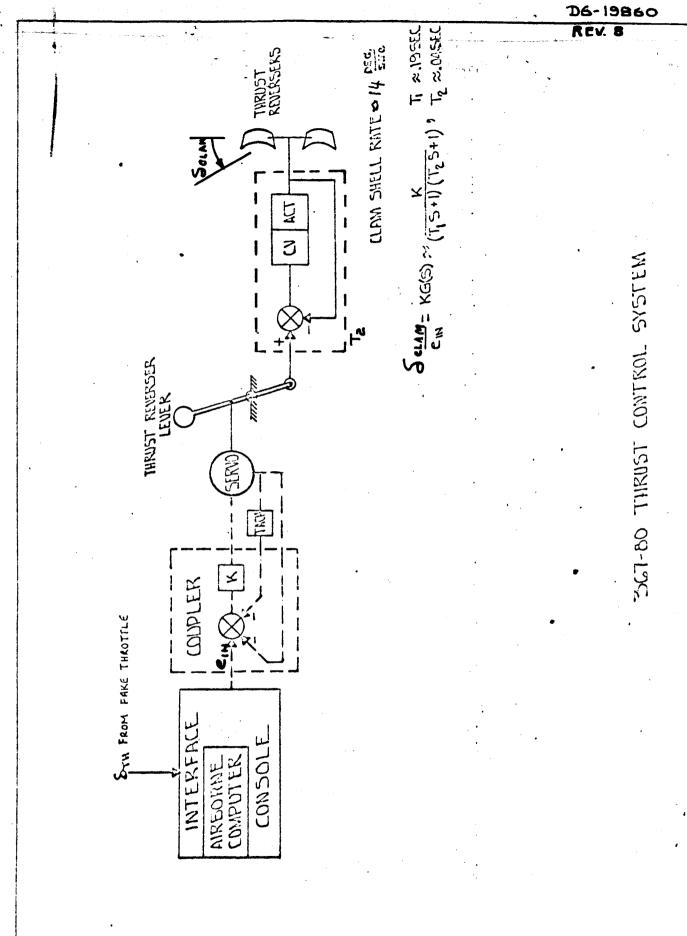
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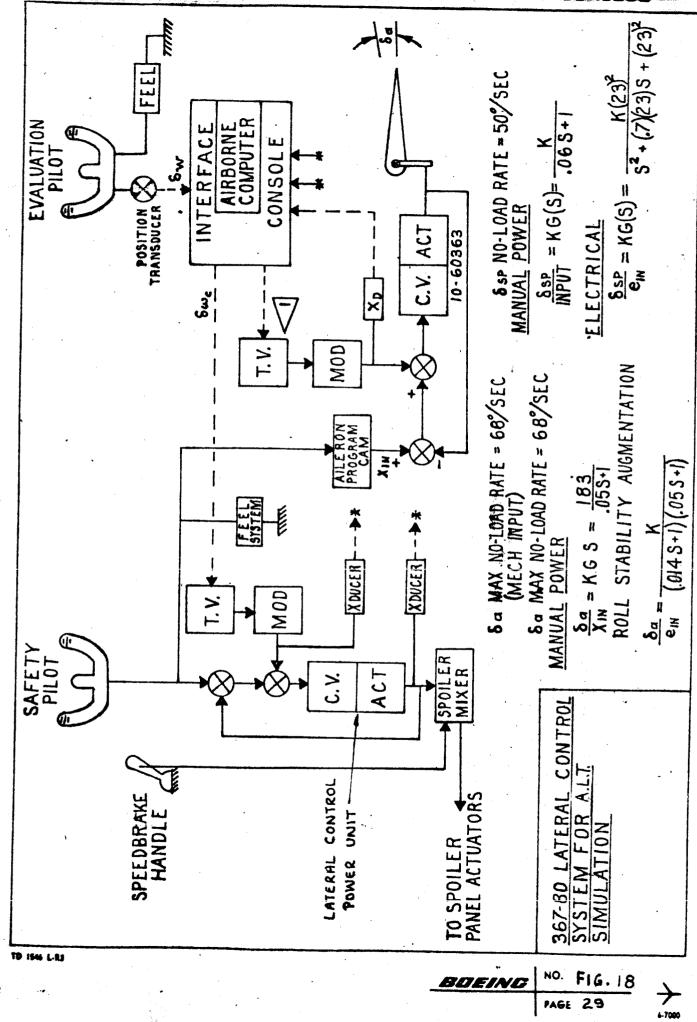


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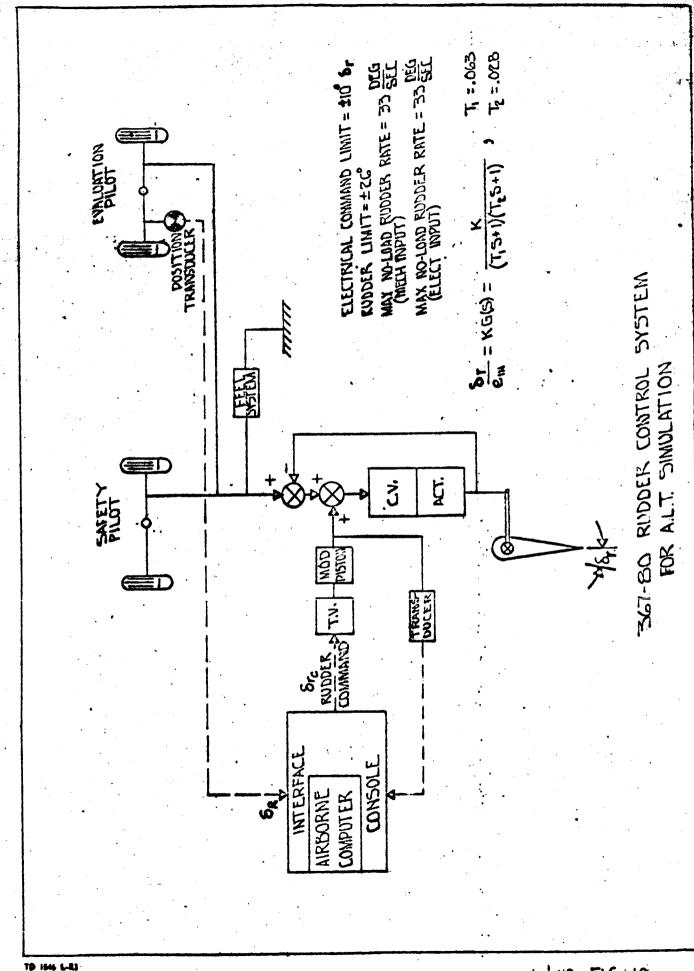
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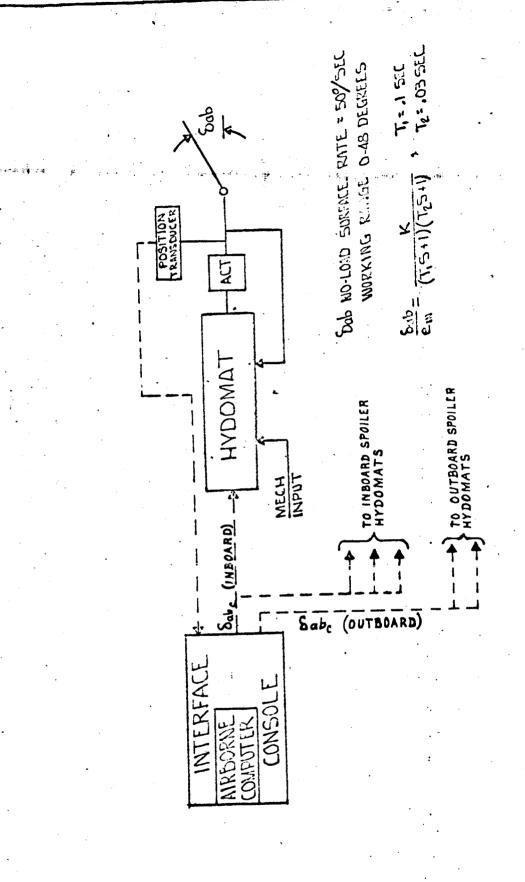


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EMERNIE NO. FIG. 19

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367-80 LIFT CONTROL SYSTEM

TD 1544 L-83

BOEING 100 FIG. 20

2.0 DESCRIPTION AND OPERATION OF SIMULATION SYSTEM

2.1 BASIC THEORY

The 367-80 in-flight variable stability system provides a five degree-of-freedom simulation of large jet aircraft operating at subsonic speeds.

The technique adopted (called response feedback) is to modulate the control surfaces of the 367-80 aircraft in such a manner as to cause the aircraft to behave in the manner predicted for the particular configuration being simulated.

The correct roll, yaw and pitch motions of the aircraft are produced by modulating the lateral controls, rudder and elevator, respectively. The correct lift and normal acceleration characteristics are obtained by modulating the wing-mounted spoiler panels, and the correct drag by modulating the engine thrust reversers. There is no simulation of side force, but studies have shown that the errors introduced by this omission are small enough to be neglected.

The controls are moved by electrical commands to the appropriate actuators or servos. The commands are produced by a Systron-Donner SD/80 general purpose analog computer which forms the heart of the simulation system. A brief step-by-step description and example of how these commands are generated follows:

a. The calculations are all based on the linearized equations of motion for a rigid airframe (see Appendix A), e.g., the pitch axis equation is:

$$I_{YY}\dot{Q} = g_0 S \in (C_{m\alpha} \cdot \Delta \alpha + C_{m\dot{\alpha}} \cdot \dot{\alpha} + C_{m\dot{q}} \cdot Q + C_{m\dot{\alpha}} \cdot \delta e + C_{m\dot{\alpha}} \cdot \delta ab + C_{m\dot{\alpha}} \cdot \Delta T + C_{m\dot{\alpha}\dot{V}} \cdot \Delta V)$$

b. The equations are used to mechanize a linearized simulation of the 367-80 airplane on the SD/80 computer; and as a basis for deriving the equations giving the summation of forces along, and the moments about, the X, Y, and Z axes. The equation for the linear acceleration experienced by the aircraft in the Z direction, for example, is:

$$\ddot{Z} = \frac{-T_0}{m} \Delta \propto -\frac{\alpha_0}{m} \Delta T - g \left(\cos \Theta_W \cos \phi_W - 1 \right)$$

$$-2 \frac{g_0 S}{m V_0} C_{L_{TRIM}} \Delta V - \frac{g_0 S}{lm} \left(C_{L_{\infty}} \Delta \propto + C_{L_{\delta_{ab}}} \cdot \delta_{ab} \right)$$

c. Now, if the 367-80 airplane is to simulate the behavior of a large transport airplane, then the linear and angular accelerations that it experiences for any given conditions must be identical to those that would be experienced by this airplane under the same conditions.

2.1.c BASIC THEORY (Continued)

Thus, the equations derived in Step b. can be written down twice; once, using the known stability and control derivatives of the 367-80 (designated by the suffix -80) and; secondly, using the predicted derivatives of the A.L.T. configuration being simulated (designated by the suffix A.L.T.). Then, using the identities,

$$\ddot{X}_{-80} = \ddot{X}_{A.L.T.}$$
 $\ddot{Y}_{-80} = \ddot{Y}_{A.L.T.}$
 $\ddot{Z}_{-80} = \ddot{Z}_{A.L.T.}$
 $\dot{\rho}_{-80} = \rho_{A.L.T.}$
 $\dot{\rho}_{-80} = \dot{\rho}_{A.L.T.}$
 $\dot{\rho}_{-80} = \dot{\rho}_{A.L.T.}$
 $\dot{\rho}_{-80} = \dot{\rho}_{A.L.T.}$
 $\dot{\rho}_{-80} = \dot{\rho}_{A.L.T.}$

these expressions can be equated, e.g., equating the pitch accelerations:

$$\dot{Q}_{-80} = \left(\frac{q_{\circ}S_{\overline{c}}}{b_{T_{\gamma\gamma}}}\right)_{-80} + \left(C_{m_{\alpha}}\right)_{-80} + \left(C_{m_{\alpha}}\right)_{-80} \cdot \Delta \alpha + \left(C_{m_{\alpha}}\right)_{-80} \cdot Q + \left(C_{m_{\alpha}}\right)_{-80} \cdot \Delta V + \left(C_{m_{\alpha}$$

From the example given it can be seen that these expressions contain a mixture of control derivative and stability derivative terms. The aerodynamic variables in the stability terms ($\Delta\alpha$, Ω , ΔV , etc., shown outside the brackets) are identical for both the -80 and the A.L.T. sides of the equation. The control variables ($\delta\epsilon$, $\delta\epsilon$ etc., shown inside the brackets) are separate and distinct.

2.1 BASIC THEORY (Continued)

d These expressions can now be solved for the control variable appropriate to the axis being considered. Thus, for the example given above, the correct pitch acceleration is maintained by modulating the 367-80 elevator, so the equation can be rewritten as follows:

$$\delta_{e-80} = \frac{K(C_{m\delta e})_{A.L.T.}}{(C_{m} \delta_{e})_{-80}} + \frac{K(C_{mat} \cdot \Delta T)_{A.L.T.}}{(C_{m\delta e})_{-80}} - \frac{(C_{m\delta t} \cdot \Delta T)_{-80}}{(C_{m\delta e})_{-80}} \cdot \Delta \propto$$

$$- \frac{(C_{m\delta ab} \cdot \delta ab)_{-80}}{(C_{m\delta e})_{-80}} + \frac{K(C_{m\alpha})_{A.L.T.} - (C_{m\alpha})_{-80}}{(C_{m\delta e})_{-80}} \cdot \Delta \propto$$

$$+ \frac{K(C_{mai})_{A.L.T.} - (C_{mai})_{-80}}{(C_{m\delta e})_{-80}} \cdot \Delta \vee + \frac{K(C_{m\alpha})_{A.L.T.} - (C_{m\alpha})_{-80}}{(C_{m\delta e})_{-80}} \cdot Q$$

$$+ \frac{K(C_{mai})_{A.L.T.} - (C_{m\delta N})_{-80}}{(C_{m\delta e})_{-80}} \cdot \Delta \vee + \frac{(C_{m\delta N})_{-80}}{(C_{m\delta e})_{-80}} \cdot \Delta \vee + \frac{(C_{m\delta N})_{-80}}{(C_{m\delta e})_{-80}} \cdot Q$$

This equation expresses the 367-80 elevator displacement (from trim position) as a function of simulated A.L.T. elevator input, A.L.T. and -80 thrust levels, -80 airbrake position, and aerodynamic variables, such that the 367-80 airplane will behave in pitch like the simulated A.L.T.

Similar expressions can be derived for the 367-80 rudder, wheel, thrust and airbrake commands.

For the full equations and derivations, see Appendix A.

e. The correct numerical values for the derivatives can now be inserted into these expressions, resulting in a set of equations which, when properly scaled, can be mechanized on the SD/80 computer using only amplifiers and potentiometers. The outputs of these amplifiers are then used as command signals to the 367-80 control surfaces to produce the required simulation.

2.2 COMPUTER MECHANIZATION (See Appendix A for basic computer diagram)

2.2.1 Patchboards

One patchboard was used for the basic Ames large transport configuration and another board, called the "-80 Checkout Board" was used to obtain in-flight information on the 367-80 control and stability derivatives.

The A.L.T. simulation board contained the following sections:

367-80 Model

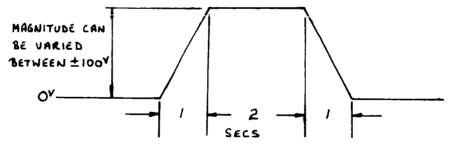
This was a linearized six-degree-of-freedom representation of the 367-80 airplane in the configuration that was set up for simulating the A.L.T.

A.L.T. Matrix

The A.L.T. Matrix was a network of amplifiers and potentiometers, derived from the equations described in Section 2.1, which generated the commands to the 367-80 control surfaces, as a result of control inputs from the Evaluation Pilot and aerodynamic feedback from the airplane sensors.

Pulse Circuit

The pulse circuit was initiated with a toggle switch and produced a pulse of the shape shown below:



The pulse circuit was used as a standard forcing function and could be applied as an elevator, rudder or wheel command either in the air or during ground checkout. A separate circuit produced a step function which could be applied as a thrust command.

Synchronizing Circuits

The synchronizing circuits were all similar and consisted basically of a chain of amplifiers whose output was integrated and used as negative feedback at the input of the chain.

If the simulator was selected but not engaged, the integrators were allowed to integrate, the effect being to keep the output of the circuit at zero. When the simulation was engaged, the

integrators were put into the "hold" condition and the outputs of the circuits became difference values.

Three of the synchronizing circuits were used for converting the values of angle-of-attack (\aleph), airspeed (\aleph) and thrust reverser clamshell door position (δ_{CLAM}) to incremental variations $\Delta \aleph$, $\Delta \aleph$, and δ_{CLAM} , respectively, about the trim values.

In addition, the $\Delta \alpha$ circuit had provisions for compensating for the nose boom position, and the δ_{CLBM} circuit contained a one second time constant. The fourth synchronizing circuit was part of the thrust servo loop and was not an inherent part of the simulation.

& and & Generating Circuits

Since neither α nor β was directly available as the output of a sensor these signals were generated in the computer.

 α was obtained by a pseudo-differentiation of α , and β from a combination of roll angle and yaw rate, $\beta = 30 - 2$.

Control Input Circuits

These circuits provided the ability to apply either the Evaluation Pilot's command inputs from the instrumented controls, or the standard pulse from the pulse circuit, to the airplane.

Function Generators

Two diode function generators were used to compensate for the basic 367-80 nonlinear characteristics of pitching moment due to thrust changes and pitching moment due to air brakes.

Interlock Circuits

The interlock circuits made it impossible to engage the simulation unless all the cables were correctly installed. In addition, one of the interlock circuits determined which elevator PCU (left or right) was to be used as the master (see 2.4.1).

Configuration Selection Circuits

The variations from the basic configuration were achieved by changing the gains of various inputs to the A.L.T. Matrix. This was done partly by changing potentiometer settings and partly by switching in additional amplifiers and potentiometers depending on the particular variation required.

An external switch box containing four double-pole, double-throw switches was used for this purpose. The details of the changes needed for the various variations are given in Appendix B.

2.2.2 Interconnections Between the SD/80 Computer and Other Equipment

The SD/80 Computer had nine cable connections on the back side. Two of these, $J10^{l_4}$ and J105 were for remote mode-selection control of the computer and connected to the Interface.

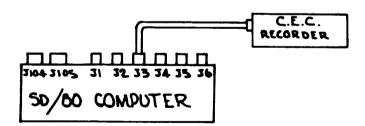
The next six, J1 through J6, had the following functions:

- J2 Provided control command inputs to the -80 model and aerodynamic parameter outputs from the -80 analog model
- J4 Provided aerodynamic and control inputs to the miscellaneous circuits listed in 2.3.1.6 and also the command outputs from the A.L.T. Matrix amplifiers to the -80 airplane control surfaces
- J3 Provided connections between the various parameters being monitored and the in-flight C.E.C. oscillograph.
- J5 Provided simulation engaged signals for the synchronizing circuits and the System Engaged Light.
- J1 Provided engaged signal to the synchronizing circuits in ground checkout operation.
- J6 Spare

The minth connector was for the main a.c. power supply.

The interconnecting cables could be hooked up in a number of different ways to produce different conditions.

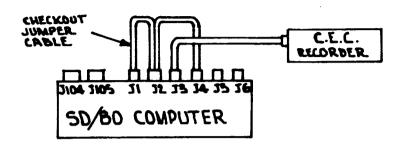
a. -80 Analog simulation ground check.



With only the connection as shown to the recorder, the -80 analog model could be used by itself and the pulse circuit output plugged directly into the appropriate command channel δe , δr , etc.

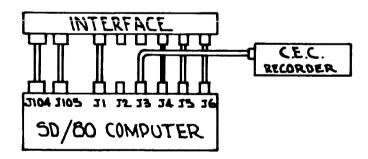
2.2.2 Interconnections Between Computer and Other Equipment (Continued)

b. A.L.T. Analog Simulation Ground Check:



With J1 and J4 connected to J2 by the "Checkout Jumper Cable" the A.L.T. Natrix was connected to the -80 analog model. In this condition the combined effect was that of an analog model of the A.L.T. configuration. It should be noted that if the A.L.T. Matrix gains were properly calculated then the same A.L.T. could be simulated with any values for the -80 derivatives. The Pulse Circuit was used to provide control inputs to the A.L.T. simulation $\delta\epsilon$, ϵ , etc.

c. In-flight A.L.T. Simulation:



With J104, J105, J1, J4, J5 and J6 connected to the correct Interface connections the A.L.T. Matrix was connected, through the Interface to the 367-80 control systems. Now, if the basic 367-80 airplane characteristics were identical to those mechanized in the -80 analog model then the airplane would respond, in the air, in the same manner as the A.L.T. model did during ground checkout.

2.3 AIRPLANE CONTROL SERVO SYSTEMS

Figures 16 through 20 show block diagrams of the five primary control systems used in the SST simulation.

2.3.1 Elevator Control System (Figure 16)

The elevator system had two parallel type actuators, right hand and left hand, in which the feedback linkage moved the Safety Pilot's column. The two actuators had different authority limits and either could be selected as the master control and the other automatically slaved to it.

The motion of the Safety Pilot's column was transmitted through a system of cables and pulleys to provide a mechanical input to the control valve that controlled the actuator which moved the elevator.

The position transducer on the Evaluation Pilot's column produced an electrical signal (δ col) that went to the computer. This signal was modified in the computer to provide the correct gain and summed with any contributions from the thrust command, air brake command, angle-of-attack, pitch rate, etc., to form an elevator command (δ eccc). When the simulation was engaged, this signal was allowed to operate either the right hand or left hand transfer valve, whichever had been selected, and the resulting motion of the modulating piston operated the control valve of the actuator, causing the elevator to move.

2.3.2 Thrust Control System (Fig. 17)

The thrust reverser clamshell doors were moved by actuators, the control valves of which were supplied with mechanical inputs from the thrust reverser levers. If the simulation was not engaged the doors could be moved independently by moving the levers singly. However, as soon as the simulation was engaged the four levers were clamped together by an electro-mechanical clutch and moved as a unit by the thrust control servo. The transducer on the fake throttle produced an electrical signal (δ TM) which went to the computer. Here it was modified to provide the correct gain and summed with any contributions from angle-of-attack, airspeed, air brake command, etc. to produce a thrust command (δ th_c). This signal operated the electro-mechanical servo through the coupler.

2.3.3 <u>Lateral Control System (Figure 18)</u>

Lateral control of the airplane was obtained by differentially operating the ailerons and spoiler panels.

Moving the Safety Pilot's wheel put a mechanical input through the summing linkage into the control valve of the lateral control power unit and moved the actuator. The output of the actuator went to the spoiler mixer where it was summed with the mechanical output from the speed brake handle. The mechanical output of the spoiler mixer was connected to the Hydomat units which drove the spoiler panels.

2.3.3 <u>Lateral Control System (Figure 18) (Continued)</u>

The transducer on the Evaluation Pilot's wheel produced a signal (δw) which went to the SD/80 computer. Here it was modified to provide the correct gain and summed with any contributions from side-slip angle, yaw rate, roll rate, etc., to produce a wheel command ($\delta \omega_c$).

In simulation mode this command operated the transfer valve on the lateral control power unit. Since this power unit was a parallel-type actuator its output fed back to move the Safety Pilot's wheel.

2.3.4 Rudder Control System (Fig. 19)

The Safety Pilot's and Evaluation Pilot's rudder pedals were coupled and provided a mechanical input through the summing linkage to the control valve on the rudder actuator. The output of the actuator moved the rudder and was also fed back to the summing linkage. In addition, the position transducer on the Evaluation Pilot's rudder pedals put out an electrical signal (δ_R) which went to the SD/80 computer. This signal was operated upon in the computer to provide the correct gain, and was summed together with any contributions from the wheel command, side slip angle, side slip rate, etc. to form the rudder command (δ_R). If the simulator was engaged, then this signal was allowed to operate the transfer valve causing the modulating piston to provide an additional input to the control valve. The modulating piston transducer provided rate feedback to the rudder command serve amplifier in the Interface.

2.3.5 Lift Control System (Fig. 20)

Lift control during the simulation was obtained by modulating the spoiler panels on the upper wing surface. The positions of the spoilers are shown in Fig. 14 where they are numbered for clarity. For the simulations covered in this document, spoilers 1, 5A, 6A and 10 were not used. The spoilers were operated by electro-hydraulic Hydomat units. Spoilers #4, 5, 6 and 7 each had a separate Hydomat Unit, but spoilers #8 and 9 were both driven by one unit and so were #2 and 3. Spoilers #2, 3, 8 and 9 are referred to as the outboard spoilers and #4, 5, 6 and 7 as the inboard speilers.

The lift modulating signals (δab_c) were produced in the computer. Because of buffeting at high spoiler angles the inboard spoilers were electrically limited to + 10 degrees. Up to this point the spoilers all moved together but above 10 degrees the gain on the outboard spoilers was doubled, by a circuit in the computer, to keep the value of C_L constant.

The mechanical input shown in Fig. 20 came from the spoiler mixer (See Fig. 18) and combined the initial trim setting from the speed brake handle and the lateral control input from the lateral control power unit.

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2.4 OPERATING PROCEDURES

2.4.1 Establishing the Basic 367-80 Characteristics

The first step in setting up a simulation was to establish a 367-80 configuration suitable for the airplane to be simulated. The factors to be considered were:

• The trimmed level flight airspeed of the 367-80 must match that required for the simulated airplane. This affected the trim thrust and flap setting.

The 367-80 was equipped with a blown flap system using engine bleed air which could be used to increase the value of CL. For the configurations described in this document it was not necessary to use this feature.

The entire simulation was flown with the 367-80 engines at constant throttle settings and thrust and drag changes were achieved by modulating the thrust reverser positions. This means that the clamshell doors had to be set initially at some partially closed position which allowed sufficient range of movement of opening and closing without limiting the simulation.

This initial angle also had to be coordinated with the constant engine output to achieve the trimmed airspeed mentioned above.

- The changes in lift coefficient during simulation were achieved by modulating the spoiler panels on the upper wing surface. These therefore had to be set up at some angle for the trim condition so that they could be modulated in both directions during simulation.
- . All simulation was performed with the landing gear down so that the approach could be continued down to touchdown.

The final configuration adopted for the 367-80 for simulating the basic A.L.T. was:

367-80 CONFIGURATION AT TRIM

Airspeed	Angle of Attack of Wing	Engine Settings (N2)	Clamshell Doors	Flaps	Spoilers	Gear
117 Knots	8.5*	96%	30°	30°	6 ° Up	Down

2.4.1 Establishing the Basic 367-80 Characteristics (Continued)

These were the nominal settings. The aircraft was trimmed in level flight by the Safety Pilot at the desired airspeed and angle-of-attack, by use of the moveable stabilizer and small throttle adjustments, prior to engagement of the simulation. Once set, the stabilizer and throttles were not moved during simulation, as all pitch and thrust changes were made with the elevators and thrust reversers.

• Flight Testing the Basic 367-80 Configuration

Once the trim configuration had been tentatively determined, the airplane was flight tested in order to obtain the following information:

- a. Confirmation and adjustment, if necessary, of the basic trim configuration (proper stall margin and body landing attitude).
- b. Documentation of the airplane characteristics. This consisted of a series of maneuvers designed to facilitate the calculation of the airplane stability and control derivatives so that an accurate analog model of the 367-80 could be mechanized on a computer.
- c. Recording of airplane responses to standard pulse inputs for confirmation and adjustment of the analog model. These recordings were used in the "overlay" technique described in Section 2.5.

The standard pulse inputs were performed using the -80 checkout board described below.

The -80 Checkout Board was a special patchboard used on the Systron Donner SD/80 Airborne Computer which contained: A six-degree-of-freedom linearized analog model of the basic 367-80; a special check pulse circuit (see 2.2.1); and provisions for connecting the Evaluation Pilot's controls through the SD/80 computer and the Interface to the airplane electro-hydraulic servo systems. The gains in the computer were selected so that the control derivatives remained identical to those of the basic airplane. Thus, the airplane characteristics were the same whether it was flown from the left-hand seat with the normal controls, or from the right-hand seat through the fly-by-wire system.

There was also provision for introducing the standard pulse into the system to simulate column, wheel, rudder or thrust commands. It should be noted that the input to the thrust was actually a step but for simplicity of writing it will be referred to as a standard pulse.

2.4.1 (Continued)

The aircraft checkout, using standard pulses, was as follows: The airplane was first trimmed in level flight at the correct airspeed and angle-of-attack by the Safety Pilot from the left-hand seat. When this condition had been achieved the simulation was engaged and the Evaluation Pilot then retrimmed the airplane, if necessary, to remove the effect of any engagement transients. When he was satisfied that the airplane was trimmed, he called for a standard pulse input from the computer. The input had already been selected to be applied to the elevator, wheel, rudder or thrust reversers. The pulse was initiated by operating a toggle switch.

The airplane response to this input was monitored by recording the following parameters on a CEC light beam oscillograph.

CHANNEL	1	2	3	14	5	6	7	8	9	10	11	12	13	14	15
VARIABLE	Sab	P	Q	-R	φ	Δ٧	Δα	-B	غ- غ	δec	δως	8rc	Polse	Sthc	SCLAM

If the input was an elevator or thrust command, the Evaluation Pilot would keep the wings level, being very careful not to initiate any longitudinal disturbances. Similarly during wheel and rudder pulses the Evaluation Pilot would maintain essentially the same pitch attitude without restraining the lateral degrees of freedom.

This technique enabled "hands-off" data to be obtained without the confusing cross-coupling effects between the longitudinal and lateral-directional axes.

The resulting airplane motion was allowed to continue sufficiently long to obtain several cycles of the phagoid mode for elevator inputs, or the catch roll mode for rudder and wheel inputs, or until the airspeed changed by 10 knots for the thrust steps.

The oscillograph records obtained during these tests were used to check the analog simulation of the basic 367-80.

• Ground Support Programs (Basic 367-80 Only)

As soon as sufficient information had been received on the basic 367-80 control and stability derivatives from the Aerodynamics Group, the gains were calculated for the analog simulation of the basic airplane and the model was set up on the -80 checkout board.

The same standard pulse inputs that were applied to the actual airplane in-flight were applied to the analog model on the ground.

The response of the model was recorded using the same oscillograph to record the same variables with the same scalings.

• Ground Support Programs (Basic 367-80 Only) (Continued)

The accuracy of the simulation and hence the accuracy of the derivatives used were checked by directly comparing the results.

This was done partly by measurement and partly by comparing the various mode shapes by directly laying the flight test results over the ground test results.

The measured values were:

- o Phugoid period and damping ratio
- o Dutch roll period and damping ratio
- o Roll angle to side-slip-angle ratio
- o Spiral time constant (time to half amplitude).

The other characteristics, which did not lend themselves to direct measurement were:

- o Longitudinal short-period characteristics
- o Initial lateral-directional response to a control input
- o Pitching moment due to thrust changes.

These were compared by direct overlay.

By making adjustments to the appropriate gains on the computer simulation, the match between the flight and ground tests could be improved and the values of the basic 367-80 derivatives refined by calculating back from the corrected gain settings. This part of the program was backed up by an additional ground based computer simulation of the basic airplane as a check on the -80 check-out board model. It should be noted that this did not confirm the validity of the model but only served to demonstrate that the simulation, as patched-up, was functioning properly.

2.4.2 Setting Up the A.L.T. Simulation

Once the control and stability derivatives of the basic 367-80 had been reasonably well established the calculations for the A.L.T. matrix were performed. These calculations were based on the theory outlined in Section 2.1, and the full equations are given in Appendix A.

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2.4.2 (Continued)

The calculations for the program covered in this document were initially done by hand using the tabulated forms shown in Appendix A, Pages Al to A32, etc., but later a digital program was set up on an IBM 7090 computer to produce this information. The program was written in a Boeing-originated computer language called BLITZ. (Further information on this language can be obtained from Boeing Document D2-36341-1, "The BLITZ User's Manual." See Ref. D.)

The A.L.T. matrix was then patched up on the A.L.T. patchboard and the correct gains set in.

Once the A.L.T. patchboard was completed, a ground simulation of the A.L.T. configuration was produced by connecting the checkout jumper cable as shown in Section 2.2.2.b.

The end result of combining the basic 367-80 analog model with the A.L.T. matrix was to produce a simulation identical to that which would result from a straight-forward simulation using the A.L.T. derivatives alone.

It should be noted here that, as long as the A.L.T. matrix calculations were correct, the basic -80 derivatives which were used in the calculations were irrelevant, as far as the ability to produce an analog simulation of the A.L.T. is concerned. In other words, a ground simulation of the particular A.L.T. could be obtained by using an analog simulation of a Piper Cub, for example, provided the A.L.T. matrix calculations were based on the Piper Cub derivatives. Naturally this would vastly affect the results obtained in the air when the real 367-80 characteristics were substituted for the analog model.

The output of the pulse circuit was then applied to the simulation to produce the responses of the A.L.T. to standard pulse inputs. The technique was similar to that described for testing the 367-80 analog model alone in Section 2.4.1 except that the pulses were applied at different terminals since it was commands to the A.L.T. elevator and rudder etc., that were required and not commands to the 367-80 elevator and rudder.

As before, the variables listed in Section 2.4.1 were recorded on the CEC Recorder, the results being checked against the results of the digital program described in the next section.

It was desired to have a completely independent means of checking the accuracy of both the analog simulation of the A.L.T. on the ground and the flight test results obtained in the air.

For this reason it was decided to utilize a digital computer to obtain data on the dynamic response of the basic A.L.T and variations.

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2.4.2 (Continued)

The Boeing TL99 digital program was used to support this phase of the work.

This program was capable of solving simultaneous non-linear differential equations and lent itself to the solution of the equations of motion of an airplane. The equations could be expressed in a block diagram form that was very similar to the computer diagram for an analog simulation of an airplane.

This block diagram was easily converted into a deck of punched cards for input to the digital computer.

Disturbing inputs, identical to the standard pulses, were introduced into the program and the resulting airplane responses became available as a time history of the aerodynamic variables whose values were tabulated at half-second intervals. The program was supplied with the calculated control and stability derivatives of the proposed A.L.T configurations and the resulting tabulated data plotted on transparent mylar to the same vertical and horizontal scales as the outputs of the CEC Recorder. The master plots could be directly overlaid on the ground and flight recordings from the CEC Recorder to determine the accuracy of the simulation.

Figures 21 and 22 show prints from two typical master overlays obtained by this program with the flight data from the CEC Recorder for the same maneuvers superimposed on the master traces.

The flight tests of the A.L.T. simulation were carried out with the SD/80 computer-to-interface cable connections as shown in Section 2.2.2.c, Page 38. The procedure used for checking the accuracy of the simulation was identical to that already described in checking out a standard pulse.

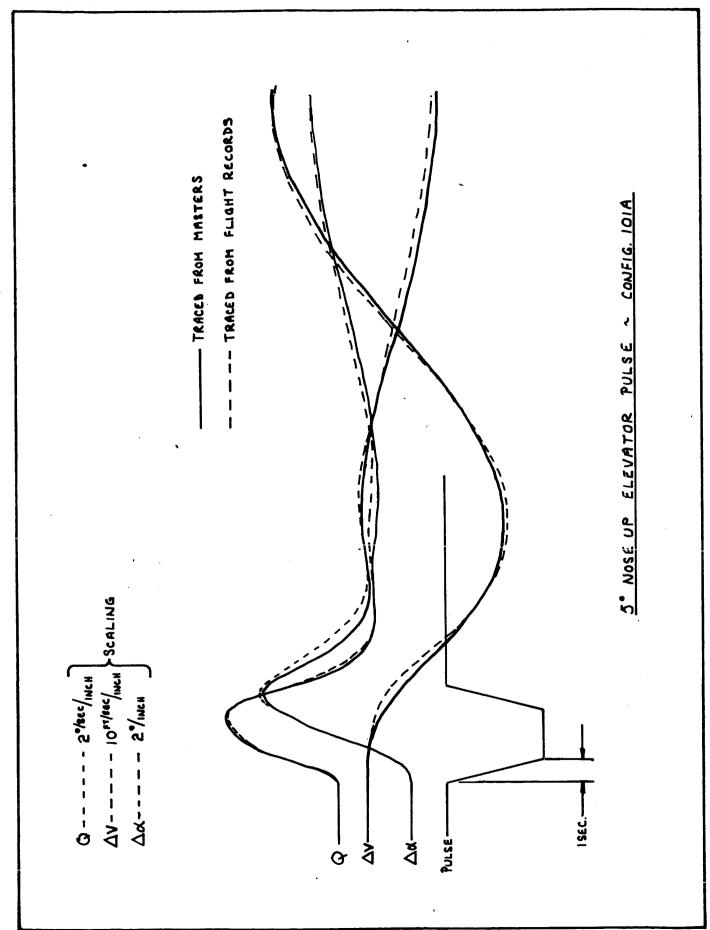
Immediately after each maneuver the in-flight recordings were checked to determine the accuracy of the simulation by direct measurement of phugoid and dutch roll periods, damping ratios, etc., and by overlaying the master traces described in the above section.

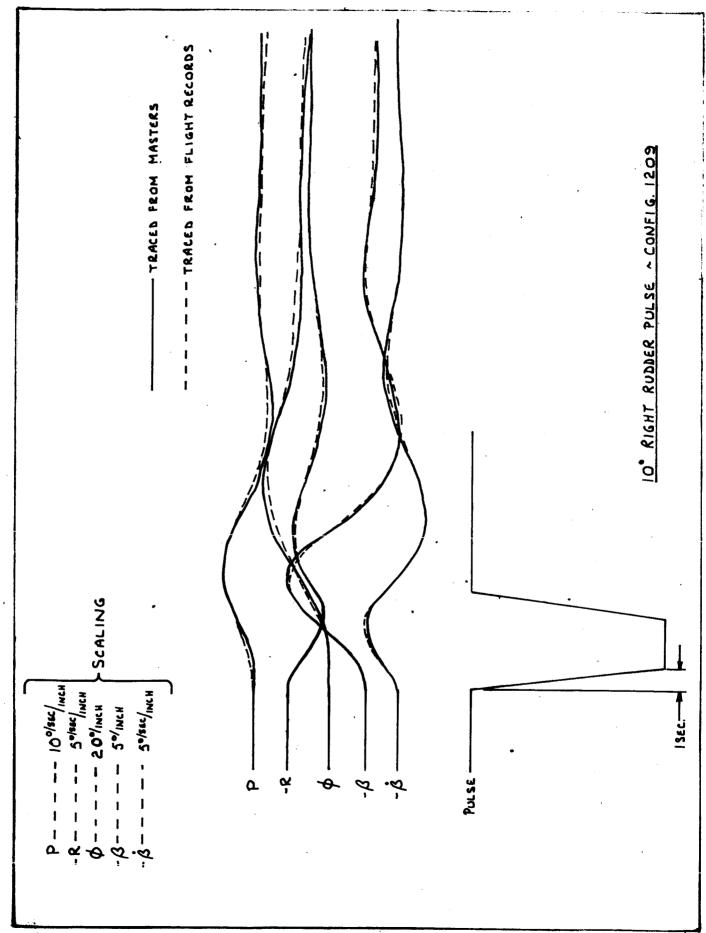
In the initial or checkout phase of the flight test program, it was necessary to "fine tune" the simulation to improve its accuracy. This was done by changing the gains of the A.L.T. matrix and repeating the check pulses as required to improve the match between the flight and ground test results.

It should be noted that, since the A.L.T. derivatives were fixed, any changes made to the gains of the A.L.T. matrix during the checkout phase were equivalent to changing the basic 367-80 derivatives.

The new 367-80 derivatives were obtained by calculating backwards from the A.L.T. matrix gains and then cranked into the analog simulation of the basic 367-80.

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2.4.2 (Continued)

Once the match was judged to be sufficiently good by the test engineer, the simulation was frozen and the test program proceeded to the documentation and pilot evaluation phases. From this point, the only changes made on the computer were those necessary to introduce the variations to the basic configuration which were to be tested, and the periodic adjustment of a special potentiometer which was varied according to the test altitude and outside air temperature to compensate for the variation in engine thrust.

During the documentation and evaluation phases, the airplane was subjected to the Standard Pulses at the beginning of each flight, and the results were examined to confirm that the simulation was still valid, before proceeding with the tests.

2.4.3 Pre-flight Checkout

The pre-flight checkout consisted of a series of ground tests that were performed as a standard procedure prior to each simulation flight.

Power was applied to the airplane and the system allowed to warm-up for at least 30 minutes before starting the pre-flight checkout.

The pre-flight checks were:

a. Computer voltage and amplifier balance checks.

The computer power supplies were checked for the correct voltage and the amplifiers checked for balance and adjusted if necessary.

b. Potentiometer Setting Checks.

All the potentiometers that were used in the simulation were checked for the correct settings by nulling them against the reference potentiometer.

c. Standard Pulse Checks.

The computer cables were connected for A.L.T. ground checkout (See 2.2.2.b Page 34) and the standard pulses applied to the elevator, thrust, wheel and rudder inputs. The resulting traces from the CEC recorder were checked against the A.L.T. masters to confirm that the computer was functioning properly.

d. Instrumentation Zeros.

At this point the command outputs from the computer were set to zero by shorting the outputs of the relevant amplifiers to the summing junctions. This was done so that the Instrumentation Engineer could record the zero references.

2.4.3 (Continued)

e. Simulation Logic Checks.

The logic circuitry was checked to ensure that the Simulation "SELECT," "ENGAGE," "RESET" controls, disconnect buttons and error detectors were working properly.

f. System Functional ("Wiggle Tests").

These tests were to ensure, as far as was possible, that the entire system was working as programmed. The computer cables were connected for in-flight simulation (see 2.2.2.c, Page 38).

To perform the tests, the airplane hydraulics were turned on and hydraulic power supplied to all the actuators; the spoiler panels set to 6°; and the clamshell doors set to 30°. The simulation was then engaged and the following tests performed:

TEST	NOTE: The values depend CHECK THAT on the A.L.T. Con- figuration and so are not quoted.				
Move Evaluation Pilot's column fully forward and aft.	Safety Pilot's wheel and -80 elevator move the correct amount and direction. Computer elevator command output is correct.				
Move the Evaluation Pilot's wheel right and left.	Safety Pilot's wheel and the -80 ailerons and spoiler panels move the correct amount and direction. Computer wheel command output is correct.				
Move the Evaluation Pilot's rudder pedals right and left.	The -80 rudder moves the correct amount and direction. Computer rudder command output is correct.				
Move the Fake Throttle forward and aft.	Clamshell doors and thrust reverser levers move the correct amount and direction. Computer thrust command output is correct.				
Move nose boom vane $\pm \alpha$, keeping β at 0.	-80 elevators and spoilers move correct amount and direction. Computer output commands are correct.				
Move nose boom vane $\pm \beta$, keeping α at 0.	-80 rudder and lateral controls move correct amount and direction. Computer output commands are correct.				
Operate Evaluation Pilot's longitudinal trim control.	-80 Elevators move up and down the correct amount				
Unbolt rate gyros and move by hand. (Hydraulics OFF)	Computer signals from gyros are correct polarity.				

2.5 SYSTEM HARDWARE DESCRIPTION

2.5.1 Cabin Controls

Figure 2 shows an overall picture of the airplane cabin. In addition to the normal airplane controls and instruments, the following are of special interest in the simulation:

The Evaluation Pilot's control column and wheel were not mechanically connected to the airplane control systems. Instead, stick and wheel position signals were obtained from potentiometers and these signals were fed through the interface to the SD/80 computer.

NOTE: The arms of the wheel were also instrumented with strain gauges, the outputs of which were averaged to give a measure of stick force. This signal was available at the computer and could be used as the Evaluation Pilot's input, but for the simulations covered in this document stick position was used.

Feel force for the Evaluation Pilot's wheel was supplied by a spring cartridge mounted on the column directly behind the wheel. The force gradient characteristics could be changed by changing the cartridge. The stick feel force was supplied by a hydraulic system which was controlled pneumatically from a pressurized nitrogen bottle. The control knob for changing the force gradient and the indicator for showing the stick force in lb/degree of stick movement can be seen at (K) in Figure 2 and also in the close-up picture, Figure 3.

The Evaluation Pilot's rudder pedals were connected mechanically to the Safety Pilot's and consequently move the 367-80 rudder through the normal control system. However, in addition, a potentiometer provided an electrical signal proportioned to pedal displacement which was used in the computer to modify the rudder during simulation.

The following descriptions all refer to the letters on Figure 2:

a. Fake Throttle Lever.

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This lever was connected to a potentiometer which put out an electrical signal to the computer and provided the Evaluation Pilot with the means to make thrust changes. Figure 3 shows a close-up of the fake throttle lever and its calibrated scale.

b. Evaluation Pilot's Disconnect Button.

The Evaluation Pilot could disengage the simulation and return control to the Safety Pilot at any time by operating this button. If disconnect occurred, the two red blinking warning lights (N) came on and the "RESET" button on the control panel (Figure 3) had to be operated before the simulation could be re-engaged (see Section 2.5.1 h.).

2.5.1 Cabin Controls (Continued)

c. Evaluation Pilot's Longitudinal Trim Control.

This was a two position, center-off switch which supplied either \pm 15 V to the computer, depending upon whether it was held in the nose-up or nose-down trim position. This voltage was integrated in the computer and the result applied as an elevator command to trim the airplane.

d. Signal Connector.

This connector carried the signals from the strain gages mentioned above.

e. Evaluation Pilot's Lateral Trim Control.

Lateral trim in simulation mode was obtained by a potentiometer which applied a bias voltage to the lateral control command signal. This signal did not go to the SD/80 computer but was added in the Interface.

f. Thrust Reverser Positioning Levers.

The standard thrust reverse levers were used to set the clamshell doors to their trim positions (approximately 30°). The clamshell door positions for the four engines were shown by the four indicators at (M).

g. Speed Brake Handle.

The normal speed brake positioning control was used to set the spoiler panels to their trim position (6° up). The position of spoiler panel No. 8 was monitored with a transducer and displayed on an indicator (L) mounted above the IRIG time display on the glareshield.

h. Simulation Control Panel.

This panel contained the controls with which the safety pilot selected the mode of operation. A close-up of this panel can be seen in Figure 4.

The selector buttons marked "YAW RATE," "YAW RATE & TCF," "RUD III," "AILERON" refer to various stability augmentation systems available on the basic 367-80 and are outside the scope of this document. The selector button marked "NORMAL" refers to a condition whereby the basic "367-80" could be flown by a "fly-by-wire" system from the right-hand seat and is also outside the scope of this document, although it resulted as a direct offshoot of this program. The controls that are directly concerned with the simulation are:

SIMULATION - when the Safety Pilot pushed this button, the simulation was selected but not engaged, and a blue light illuminated the left-hand section marked "SEL." The Safety Pilot selected this condition prior to

2.5.1.h (Continued)

trimming the airplane. In this condition the mode control logic in the Interface put the SD/80 computer into the "COMPUTE" mode (it was previously in "RESET") which allowed the synchronizing circuits for $\Delta\alpha$ and ΔV to start operating. The Evaluation Pilot's controls were still disconnected from the system. When the aircraft was trimmed the Safety Pilot pushed the "PUSH TO ENGAGE" button.

"PUSH TO ENGAGE" - This control engaged the simulation and activated the analog gates in the Interface allowing the command outputs from the SD/80 computer to be applied to the control surface actuators. Simultaneously the $\Delta\alpha$ and ΔV synchronizing circuits in the computer were put into the "HOLD" condition; the "ON" portion of the "SIMULATION" control button was illuminated with a green light and the "simulation engaged" light on the computer patchboard was turned on. The simulation could be disengaged by pulling up on the "PUSH TO ENGAGE" button but this feature was seldom used.

"RESET" - This control was used to reset the mode selection logic in the Interface if the simulation had been disengaged as a result of an error in the system or because the Evaluation Pilot had operated his disconnect button.

j. Safety Pilot's Disconnect Button.

By operating this control the Safety Pilot could disengage the simulation at any time and regain control of the airplane. The simulation mode changed from "ON" to "SELECTED."

k. Evaluation Pilot's Stick Feel Force Control and Indicator.

Described previously.

1. Spoiler Panel No. 8 Position Indicator.

Described previously.

m. Thrust Reverser Clamshell Door Position Indicators.

Described previously.

n. Simulation Disconnected Warning Lights.

These were two large red blinking warning lights that came on if the simulation was disengaged either by an error in the system or by the Evaluation Pilot's disconnect button. These lights did not go out until the Safety Pilot's Disconnect Button was operated.

o. Simulation Limits Warning Lights.

These five amber warning lights for the rudder, spoiler, elevator, lateral control and thrust servo systems indicated when the servo amplifier

2.5.1 o. (Continued)

error signal had been exceeding a predetermined threshold value for more than half a second. This did not result in an automatic disconnect but indicated that the accuracy of the simulation was in doubt.

p. Reference Airspeed Setting Indicator.

The airspeed signal to the computer was the difference between the value obtained from the Pitot-Static System and the value set into the reference airspeed indicator. The latter value was set to the normal trim speed, by means of the knob at the lower left corner of the indicator, to prevent over-loading of the ΔV synchronizing circuit.

2.5.2 Systron-Donner SD/80 Analog Computer

The Systron-Donner SD/80 computer used on this program was basically a productionline desk-top type computer (Figure 5, Page 16 shows the computer as it was mounted in the airplane). Certain modifications were made at the factory prior to shipment. These were:

- a. The addition of special shock mounts designed for the vibration environment in the airplane.
- b. The ruggedizing of the amplifier module mounting system.
- c. The potting of the amplifier components on the printed circuit boards.
- d. The addition of a heater and fan, controlled by a toggle switch so that the computer could be purged with warm air. This provision was added because of the possibility of moisture condensation in the computer when the airplane stood outside overnight.
- e. The addition of warning lights to indicate an overtemperature condition. This provision was added because the computer was used on the ground at times when the airplane air-conditioning system was not operating.
- f. Modification to the power supplies to enable the computer to be operated from a 400 cps supply instead of 60 cps.

The computer contained 84 solid state operational amplifiers which were mounted in pairs on removable modules directly behind the patchboard (see Figure 5, Page 16).

The modules contained additional components which determined the type of operation for which they could be used; i.e., summing amplifiers, inverting amplifiers, or integrators.

As used for this program the computer had 44 summers, 18 inverters and 22 integrators. In addition, there were 18 double-pole, double-throw relays mounted in pairs on 9 of the modules.

2.5.2 (Continued)

The computer had two moveable wings on which the controls were mounted. The left-hand wing contained: (Referring to Figure 5)

- a. Fifteen diode function generators in removable modules mounted in a receptacle behind this panel.
- b. The overheat warning lights and the heater toggle switch.
- c. A voltmeter which could be used either as a direct reading instrument or as a nullmeter.
- d. The address selector switches for monitoring the output of any particular amplifier or potentiometer on the panel meter.
- e. The top six switches were for selecting one of six direct-reading panel meter scales (± 300V, ± 100V, + 30V, ± 10V, ± 3V, ± 1V) to 2% of full scale accuracy. The two botton switches selected either ± NULL for measuring any problem voltage with an accuracy of 0.01% of full scale by comparison with a reference voltage selected by the reference potentiometer.
- f. Four-digit reference potentiometer.
- g. Panel containing operating controls and indicators. These are: Four push-button/indicators for selecting HOLD, COMPUTE, RESET and REP-OP Modes.
- . Time scale control (not used in this simulation).
- Slave switch for selecting either local control at the computer or external control through the Interface.
- . Power-on switch.
- . Indication for oven-power, amplifier overload, etc.
- h. Five single-pole, double-throw toggle switches with center-off position, and five potentiometers for gain adjustment.

The right-hand wing contained 120 more potentiometers for gain adjustment.

2.5.3 Interface

The Interface is shown in Figure 6 as it was mounted in the airplane. Some of the equipment in the interface was concerned with basic 367-80 stability augmentation systems and is outside the scope of this document. A full description of the Interface can be obtained from Boeing Document D6-19857 "Variable Stability Interface Installation in 367-80 Airplane." (Reference E). The equipment associated with the variable stability system is, referring to Figure 6:

a. Section containing the servo amplifiers and associated electronics for the spoiler panel servos.

2.5.3 (Continued)

- b. Controls for monitoring the outputs of the various amplifiers in the Interface, and for selecting the panel meter full scale deflection values.
- c. This panel contains duplicate simulation mode controls, similar to the controls in the cabin, and error-indicating lights.
- d. Lateral control servo amplifiers and associated electronics.
- e. Elevator servo amplifiers and associated electronics.
- f. Rudder and alleron servo amplifiers and associated electronics.
- g. Isolation networks, demodulation, etc.
- h. This section contains the mode control logic digital circuits.
- i. Isolation networks.
- j. Power distribution and control circuits.

2.5.4 Airplane Sensors

The following sensors were used to provide aerodynamic data to the computer.

• Angle-of-Attack and Sideslip Sensor ($\alpha\beta$ Vane)

Figure 7 shows the $\alpha\beta$ vane as it was mounted on the nose boom. This vane was specially designed by Giannini to have a very good low frequency response characteristic and a natural frequency of about 23 cps. The vane was supported on two gimballs whose angles were monitored by low friction potentiometers. The tip of the beam was bent down so that high angles of attack, up to 30° could be accommodated without reaching the mechanical limit of the vane.

Rate Gyros

Pitch, roll and yaw rate information was obtained from two rate gyro packages mounted in the lower 41 section of the airplane. The roll-rate gyro was the smaller package on the right in Figure 8. The larger package was a 3-axis gyro which was used for pitch and yaw rates.

. Vertical Gyro

Not shown on Figure 8 but directly below the rate gyros was a vertical gyro which provided roll angle information.

Airspeed Sensor

The airspeed signal was obtained from the pilot's pitot static system, the output of which fed the airspeed synchro.

2.5.4 (Continued)

The final output of the airspeed system that went to the computer was a voltage that indicated the incremental difference of the airspeed above or below the value set on the pilot's reference airspeed instrument.

2.6 AMES LARGE TRANSPORT BASIC CONFIGURATION AND VARIATIONS SIMULATED

A basic assumption of the simulation was that no cross-coupling existed between the lateral-directional and longitudinal axes and that it was possible to vary the lateral and longitudinal characteristics of the simulated airplane independently.

The various configurations, lateral and longitudinal, were given configuration numbers for identification purposes. These configuration numbers and the significant changes from the basic configuration are listed in the following tables. In each case, the first configuration listed is the basic and corresponds to the full set of derivatives for the Ames Large Transport given in the description sheet in Appendix A, Sheet A30. The modification to the computer diagram required to achieve the variations and the corresponding calculations and BLITZ Program outputs are given in Appendix B.

Table I Lateral-Directional Configurations

	RE	QUIRED INDE	DEPENDENT CHARACTERISTICS				
COMFIG.	MAX. WHEEL ANGLE (Sw max.) (DEGREES)	MAX. WHEEL RATE (Swr max.) (DEG./SEC.)	WHEEL SENSITIVITY Class (RAD.	ROLL T	TME CONST. C1 p /RAD./SEC	Max. Steady State Roll Rate (P max) DEG./SEC.	Acceler.
1209 BASIC	75	375	.0973	1.14	2442	26.2*	14.3*
1203A	30	150	.1457	1.14	2442	26.2*	14.3*
1207A	30	150	.0912	1.14	2442	9.75	8.6
1235	50	250	.0915	.6	510	8.6	14.3*
1237	50	66	.0915	1.14	2442	16.0	14.3*

^{*}These values were limited by basic 367-80 characteristics.

2.6 (Continued)

Table II Longitudinal Configurations

		Corresponding Derivatives						
Config.	Short Pe	riod Fre-	Lift Coeff. Due to	Elevator to Column	Elevator Power	Deriv		
	Ratio	quency Wn	Elevator CL _{Ss}	Se/Scor.	Cmse	Cmx	Cmq	
100 (Basic)	.71	• 9 3	+.40	1.5	-1.56	-2.0	-2.4	
101A	.71	• 9 3	+.40	1.5	-2.3	-2.0	-2.4	
105*	.71	•93	+.40	4.5	-1.56	-2.0	-2.4	
105A	.71	•93	+.40	3.0	-2.3	-2.0	-2.4	
151	.71	•93	40	1.5	-1.56	-2.0	-2.4	
151B	-71	•93	40	1.5	-2.3	-2.0	-2.4	
151C	.71	•93	.00	1.5	-2.3	-2.0	-2.4	
151D	.71	•93	40	3.0	-2.3	-2.0	-2.4	
158	.71	1.28	+.40	3.0	-1.56	-4.0	-j+⁻8	
158A	.71	1.28	+.40	3.0	-2.3	-4.0	-4.8	
159	.87	1.08	+.40	1.5	-1.56	-2.0	-4.8	
159A	.87	1.08	+.40	1.5	-2.3	-2.0	-4.8	
15 93	.87	1.08	+.40	3.0	-2.3	-2.0	-4.8	
161	.96	.67	+.40	3.0	-1.56	-0.5	-2.4	
161B	.96	.67	+.40	3.0	-2.3	-0.5	-2.4	

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3.0 PROBLEM AREAS

A certain number of problems were encountered in the program that are inherent to this type of simulation. They are briefly summarized below.

3.1 Derivatives

Because the simulation depended upon the calculated differences between the 367-80 derivatives and the simulated A.L.T. derivatives, it was more difficult to simulate airplanes that were radically different from the 367-80. This was particularly true of the variations which had a low value of $C_{\rm M}$.

3.2 Linearized Equations

The simulation was based on linearized equations of motion and consequently any variables that were actually non-linear over the range of the simulation affected the accuracy of the simulation. This situation could be improved by using function generations for the most non-ninear variables provided, of course, that the functions could be accurately defined. In the simulation, function generators were used to compensate for the 367-80 pitching moments due to thrust and spoilers, which are both non-linear.

3.3 True Trim Condition

Since the simulation was based on perturbation equations and the variables were all incremental values about a trim condition it was extremely important that the trim condition be established as accurately as possible. Any variation from the true trim condition before the simulation was engaged affected the subsequent airplane behavior.

3.4 Turbulence

The effect of turbulence on the accuracy of the simulation was very marked. This was because the output of the $\alpha\beta$ vane fed directly into the computer and any output which was the result of a gust rather than a true change in the angle-of-attack of the wing produced an erroneous elevator command and affected the behavior of the airplane. To maintain the required confidence level in the results the flight testing was limited to conditions of zero to light turbulence.

REFERENCES

- A. Boeing Document D6-19856. "367-80 Airplane Variable Stability Simulation Bystem (NASA Langley Supersonic Transport Simulation Program)." (NASA CR-66126)
- B. Boeing Document D6-10743. "Simulation of Three Supersonic Transport Configurations with the Boeing 367-80 In-Flight Dynamic Simulation Airplane." (NASA CR-66125)
- C. Boeing Document D6-15000. "Large Transport Landing Characteristics as Simulated in Flight and on the Ground." (NASA CR-62036)
- D. Boeing Document D2-36343-1. "The BLITZ User's Manual."
- E. Boeing Document D6-19857. "Variable Stability Interface Installation in 367-80 Airplane."

6

В

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LINEARIZED - BO EQUATIONS OF MOTION

$$\Delta \dot{V} = -\frac{\rho S V_o}{m} C_{DTRIM} \Delta V - \frac{\rho S V_o^2}{2m} \left(C_{Doc} \times \Delta \infty + C_{DSab} \times \delta ab \right) + \frac{1}{m} \Delta T - 8 \ \delta$$

$$\dot{\delta} = \frac{\rho SV_o}{2m} \left(C_{Loc} \times \Delta \alpha + C_{LS_{ab}} \times \delta_{ab} + C_{LS_e} \times \delta_e \right) + \frac{T_o \Delta \alpha}{mV_o} + \left(\frac{2e}{V_o \Sigma} - \frac{T_o \alpha_o}{mV_o \Sigma} \right) \Delta V + \frac{\alpha_o}{mV_o} \Delta T$$

$$R_{w} = \frac{pSV_{o}}{2m} \left(C_{Y_{g}} \times \beta + C_{Y_{p}} \times P + C_{Y_{g}} \times R + C_{Y_{g}} \times \delta_{w} + C_{Y_{g}} \times \delta_{r} \right) + \frac{9}{V_{o}} \Phi$$

$$\dot{\alpha} = Q - Q_w$$
; $\Delta \alpha = \int \dot{\alpha} dt$; $\delta = \int \dot{\delta} dt$

$$\dot{B} = R_{\omega} - R$$
; $\dot{B} = \dot{\beta} \dot{B} dt$; $\dot{\phi} = \dot{\beta} P dt$

In these equations the following variables are:

in radians: Da, B, Sw, Sr, Se, Sab, O, O

in radians/sec: &, B, P, Q, R, X, Rw

in feet/sec: DV

in lbs : ΔT

These equations are derived from WADC, Technical

Note 55-747 by R.M. Howe, June 1956.

They are valid for small perturbations around the trimmed level flight condition.

Eliminating R_w and changing the units of the variables to the following: in degrees: $\Delta \infty$, β , δ_w , δ_r , δ_e , δ_a , δ , ϕ .

in degrees/sec: à, B, P, Q, R, X.

(α_0 in degrees) in feet/sec: ΔV

in pounds: DT

P= 9.56 (Clox B+ Clpx P+ Clxx R+ Clsw x 8w+Clsv x 8r)

Q= 9. Sc (Cmx Δα + Cmix α + Cmq x Q + Cmse be + Cmse bab + 57.3 Cm ΔT × ΔT)

 $\dot{R} = \frac{9.5b}{L_{ZZ}} \left(C_{n\beta} * B + C_{np} * P + C_{nR} * R + C_{n\delta\omega} * \delta_{\omega} + C_{n\delta r} * \delta_{r} \right)$

 $\dot{N} = -\frac{\rho S V_0}{m} C_{DTRIM} \Delta V - \frac{\rho S V_0^2}{2m \times 57.3} \left(C_{Oo} \times \Delta \alpha + C_{OSab} \times \delta_{ab} \right) + \frac{1}{m} \Delta T - \frac{9}{57.3} \delta_{ab}$

 $\dot{\delta} = \frac{\rho S V_o}{2m} \left(C_{L\alpha} \times \Delta \alpha + C_{L\delta_{ab}} \times \delta_{ab} + C_{L\delta_{e}} \times \delta_{e} + \frac{T_o \Delta \alpha}{m V_o} \right) + 57.3 \left(\frac{28}{V_o 2} \right) \Delta V - \frac{T_o \alpha_o}{m V_o} \Delta V + \frac{\alpha_o}{m V_o} \Delta V$

 $\dot{\beta} = \frac{\rho \, \text{SV}_{\bullet}}{2m} \left(C_{Y_{\bullet}}^{\mu} \beta + C_{Y_{\bullet}}^{\mu} p + C_{Y_{\bullet}}^{\mu} R + C_{Y_{\bullet}}^{\mu} S_{\bullet} + C$

·= Q - δ

7

 $\Delta \alpha = \int \dot{\alpha} dt$; $\beta = \int \dot{\beta} dt$; $\delta = \int \dot{\delta} dt$; $\Phi = \int Pdt$

In these equations the aerodynamic and control coefficients

have the following units: /LB : Cmar

Radian: CAB, CASW, CAST, CMC, CMSe, CMSab, Cng, Cnsw, Cnsr, Coa, Cosab, Cyg, Cysw, C

sec/radion: Cop, Cop, Cmc, Cmq, Cnp, Cnp, Cypfy

THE FOLLOWING SCALE FACTORS WILL BE USED:

$$-5\beta$$
, Q, $-5\dot{6}$, $5\dot{6}$, $5\Delta\alpha$, 5δ , ΔV , $-5P$, $-10\dot{\beta}$, $+5\dot{\beta}$, -2ϕ , $\pm 10R$, $5.25\delta_{e_e}$, $\pm 10\delta_{ab}$, $\pm 10\delta_{r_e}$, $+\delta_{\omega_e}$, $\pm 3\delta_{th_e}$, where $3\delta_{th_e}$ in degrees = $\frac{\Delta T}{278}$

$$-5P = -\int \left[\frac{905b}{bT_{xx}}\left(-C_{\ell\beta}\right)\left(-5\beta\right) + \frac{905b}{bT_{xx}}\left(\frac{C\ell_{Sr}}{2}\right)\left(10\delta_{r_c}\right) + \frac{905b}{bT_{xx}}\left(5.0C_{\ell\lambda}\right)\left(5.0C_{\ell\lambda}\right)\right) + \frac{905b}{bT_{xx}}\left(\frac{C\ell_{e}}{2}\right)\left(10R\right) + \frac{905b}{bT_{xx}}\left(-C\ell_{p}\right)\left(-5P\right)\right] dt$$

$$-10R = -\int \left[\frac{9.5b}{I_{zz}}(-2C_{np})(-5P) + \frac{9.5b}{D_{Izz}}(10C_{n_{Sw}})(\delta_{\omega_{c}}) + \frac{9.5b}{D_{Izz}}(-C_{n_{Sw}})(-10\delta_{r_{c}}) + \frac{9.5b}{D_{Izz}}(-C_{n_{R}})(-10\delta_{r_{c}}) + \frac{9.5b}{D_{Izz}}(-C_{n_{R}})(-10\delta_{r_{c}}) + \frac{9.5b}{D_{Izz}}(-C_{n_{R}})(-10\delta_{r_{c}}) + \frac{9.5b}{D_{Izz}}(-C_{n_{R}})(-10\delta_{r_{c}}) + \frac{9.5b}{D_{Izz}}(-C_{n_{R}})(-10\delta_{r_{c}}) + \frac{9.5b}{D_{Izz}}(-C_{n_{R}})(-10\delta_{r_{c}})$$

$$5\dot{B} = -\left[\frac{\rho SV_{o}}{2m}\left(-C_{V_{B}}\right)(5\beta) + \frac{\rho SV_{o}}{2m}\left(C_{V_{P}}\right)(-5P) + \left(.5 - \frac{\rho SV_{o}}{2m}\frac{C_{V_{B}}}{2}\right)(10R) + \frac{\rho SV_{o}}{2m}\left(-5.0C_{V_{Sw}}\right)(\delta_{w_{e}}) + \frac{\rho SV_{o}}{2m}\left(\frac{C_{V_{SY}}}{2}\right)(-10\delta_{V_{o}}) - \frac{2.59}{V_{o}}\left(-2\phi\right)\right]$$

$$-2\phi = -4\int (.5P) dt$$

$$-5B = -\int (5\dot{B}) dt$$

$$\begin{split} -5 \dot{\delta} &= + \frac{\rho S V_o}{2 \, \text{rm}} \left(\frac{C_{LS,e}}{1.0 \, \text{S}} \right) \left(5.25 \, \delta_{e_e} \right) + \frac{1390 \, \alpha_o}{m V_o} \left(3 \, \delta_{Lk} \right) + \frac{\rho S V_o}{2 \, \text{m}} \left(5 \, C_{LS,k} \right) \left(-10 \, \delta_{kk} \right) \\ &+ \left(\frac{\rho S V_o}{2 \, \text{rm}} \, C_{L_{oc}} + \frac{T_o}{m V_o} \right) \left(5 \, \Delta \alpha \right) - \left[286 \left(\frac{2.2}{V_o^2} \right) - \frac{5 T_o \alpha_o}{m V_o^2} \right] \left(\Delta V \right) \\ \Delta V &= - \int \left[\frac{278}{m} \left(-3 \, \delta_{Lk_o} \right) + \frac{\rho S V_o}{m} \, C_{D_{TRIM}} \left(\Delta V \right) + \frac{\rho S V_o^2}{2 \, \text{m} \, \text{s} \, \text{S} \, \text{S}} \left(\frac{C_{D_0}}{5} \right) \left(5 \, \Delta \alpha \right) \right. \\ &+ \frac{\rho S V_o^2}{2 \, \text{m} \, \text{s} \, \text{S} \, \text{T} \, 3} \left(-\frac{C_D \, S_{ak}}{10} \right) \left(-10 \, \delta_{ak} \right) + \frac{2.2}{513} \left(5 \, \delta V \right) \right] \, dt \\ Q &= - \int \left[\frac{9.5 \, c}{L_{YY}} \left(-57.3 \, C_{m_{BN}} \right) \left(\Delta V \right) + \frac{9.5 \, c}{1 \, \text{T} \, \text{YY}} \left(-.2 \, C_{m_{CL}} \right) \left(5 \, \Delta \alpha \right) \right. \\ &+ \frac{9.5 \, c}{0 \, \text{T} \, \text{YY}} \left(276 \, \times 57.3 \, C_{m_{BN}} \right) \left(-3 \, \delta_{Lk_o} \right) + \frac{9.5 \, c}{0 \, \text{T} \, \text{YY}} \left(-.1 \, C_{m_{Co}} \right) \left(10 \, \delta_{ak} \right) \right. \\ &+ \frac{9.5 \, c}{1 \, \text{T} \, \text{YY}} \left(-\frac{C_{m_{Soc}}}{5.25} \right) \left(5.25 \, \delta_{C_0} \right) + \frac{9.2 \, S^2}{0 \, \text{T} \, \text{YY}} \left(-.2 \, C_{m_{CO}} \right) \left(5 \, \dot{\alpha} \right) \right. \\ &+ \frac{9.5 \, c}{0 \, \text{T} \, \text{YY}} \left(-C_{m_{Co}} \right) \left(0 \right) \right] \, dt \\ &-5 \, \dot{\alpha} = - \left[5 \, \left(Q \right) \, + \left(-5 \, \dot{\alpha} \right) \right] \\ &= 5 \, \Delta \alpha = - \int \left(-5 \, \dot{\alpha} \right) \, dt \right. \end{aligned}$$

The above equations are written in the body axes. In order to convert to stability axes and also to include the effect of the cross-product of inertia, I_{xz} , the following changes were made in both the -80 and the A.L.T. calculations:

a.) The moments of inertia I_{xx} , I_{yy} , I_{zz} , I_{xz} were converted from body axes to stability axes I'_{xx} , I'_{yy} , I'_{zz} , I'_{xz} , using the equations:

$$I'_{XX} = I_{XX} \cos^2 \alpha + I_{ZZ} \sin^2 \alpha - 2I_{XZ} \sin \alpha \cos \alpha$$

$$I'_{YY} = I_{YY}$$

$$I'_{ZZ} = I_{ZZ} \cos^2 \alpha + I_{XX} \sin^2 \alpha + 2I_{XZ} \sin \alpha \cos \alpha$$

$$I'_{XZ} = (I_{XX} - I_{ZZ}) \sin \alpha \cos \alpha + I_{XZ} (\cos \beta \alpha - \sin^2 \alpha)$$

- 1.) The effect of the cross-product of mertia was included by:
 - i) Replacing I'_{xx} by $I'_{xx} \frac{I'_{xz}^2}{I'_{xz}}$ and I'_{zz} by $I'_{zz} \frac{I'_{xz}^2}{I'_{xx}}$ i) Replacing C_{lg} by $C_{lg} + \frac{I'_{xz}}{I'_{zz}} C_{ng}$ C_{lp} by $C_{lp} + \frac{I'_{xz}}{I'_{zz}} C_{np}$ etc...

 and C_{ng} by $C_{ng} + \frac{I'_{xg}}{I'_{xx}} C_{lg}$ C_{np} by $C_{np} + \frac{I'_{xg}}{I'_{xx}} C_{lg}$

etc...

$$\begin{cases} s = .5pN^{2} \\ s = 46.4 \\ s = 130,894 = 130.8 = 17.12 \times 10^{6} \\ s = 130,894 = 10.1 = 2.631 = 10^{6} \\ s = 130,894 = 10.1 = 2.631 = 10^{6} \\ s = 17.12 \times 10^{6} = 6.66 \\ \hline \frac{g \cdot Sb}{D \cdot I_{XX}} = \frac{17.12 \times 10^{6}}{2.57 \times 10^{6}} = 1.169 \\ \hline \frac{g \cdot Sb}{D \cdot I_{YY}} = \frac{2.631 \times 10^{6}}{2.75 \times 10^{6}} = 3.619 \\ V_{o} = \frac{17.12 \times 10^{6}}{4.13 \times 10^{6}} = 3.619 \\ V_{o} = \frac{39.01 \times 10^{3}}{4.13 \times 10^{5}} = 920.35 \times 10^{5} \\ \hline \frac{Cc}{mV_{o}} = \frac{39.01 \times 10^{3}}{920.35 \times 10^{3}} = .9236 \times 10^{-5} \\ \hline \frac{ToC_{o}}{mV_{o}} = \frac{18.194 \times 8.5}{4660 \times 39.01 \times 10^{3}} = .8507 \times 10^{-3} \\ \rho = .002377 \\ \rho S = .002377 \times 2821 = 6.7055 \\ \hline \frac{pS}{2m} = \frac{6.7055}{4660} = .001439 \\ \hline \frac{pSV_{o}}{2m} = \frac{6.7055 \times 197.5}{2 \times 4660} = .1421 \\ \hline \frac{pSV_{o}}{2m} = \frac{6.7055 \times 197.5}{9320} = .1630 \\ \hline \frac{29}{V_{o}} = \frac{32.2}{197.5} = .1630 \\ \hline \frac{29}{V_{o}} = \frac{44.4}{39.01 \times 10^{3}} = .00165 \\ \hline \end{cases}$$

			36	DOJANA 08-FG
	POTENT	TIOMETER	MDIABLE	
	NO.	SETTING	VARIABLE	MORT GETALUSIAS
	42	.0704	+5.25 60	+ 1 105 CL Se 2m
33	43	.0128	+ 36ehc	+ 1390 (\alpha o \)
AMPL	44	.0575	-108abc	5 CL sab 12m
Z	45	0 <i>0e</i> F.	+ 51x	$+ C_{Loc} \frac{SV_o}{2m} + \left(\frac{T_o}{mV_o}\right)$
	46	.4ଜୀବ	+ 64	$+286\left(\frac{2e}{V_0}\right)-\left(\frac{5T_0\alpha_0}{mV_0^2}\right)$ $\alpha_0=\alpha_{TRIM,WING}^{INDEK}$
	47	<i>587</i> 0.	-36 thc	
75	48	.0395	+ 🚧	+ CDTRIM (PSVO)
DRAG AMPL 31	49	. 0533		+ Coc (.105/2)
ON	50	0	-108abc	- Cosab (105Vo2)
	51	.1124	+ 58	+ 29 + 513
	40	<i>00</i> ~0.	+ 🗸	- 57.3 Cm 25.16 -
	53	.2 59 5	+500	-2Cma (")
35	54	0	- 36the	+57.3×276 C _{mar} (")
PITCH	うち	.0150	+ 106 abe	1 Cmsab (")
PAP	56	.የደገ2	+5.256 _{ec}	2Cmse (")
	57	.0634	+5à	-2Cmác (")
ار	58	.8273	+ 0	- Cmg (")
AMPI 18	59	.5000	+ 9	SCALE FACTOR

	367-80 ANALOG											
	POTEN	NTIOMETER	VARIABLE	CALCINI ATE D. EDOM								
	NO.	SETTING	MAKINDLE	CALCULATED FROM								
:	<i>አ</i> ታ	<u>9</u> 17711.	-58	$\left(C_{1g} + \frac{I_{xx}}{I_{xx}} C_{ng} \right) \left(\frac{q \cdot Sb}{I_{xx}^2 - \frac{1}{2} \frac{1}{x^2}} \right)$								
٦	23	.0544	+108rc	$-\left(C_{1g} + \frac{I_{XB}}{I_{ZB}} C_{ng}\right)\left(\frac{q \cdot Sb}{I_{XX}^2 - \frac{I_{XB}}{I_{ZB}}}\right) + 5\left(C_{1g} + \frac{I_{XB}}{I_{ZB}} C_{ng}\right)\left(\begin{array}{c} q \cdot Sb \\ I_{XX}^2 - \frac{I_{XB}}{I_{ZB}} \end{array}\right)$								
ROLL	24	.2005 ^{<u>10</u>}	+ 8 _{wc}	+ 5 (CRS + I'EE CRSW) ")								
4	25	.3545	+IOR	+.5(Cer+ I's Cnr)(")								
	26	.B000	-5P	$-\left(C_{1p}+\frac{I_{XE}^{\prime}}{I_{ZE}^{\prime}}C_{np}\right)(")$								
YAW AMPL.21	27	.1000	-5P	$-2\left(C_{np}+\frac{I_{xx}^{\prime}}{I_{xx}^{\prime}}C_{pp}\right)\left(\frac{9.5b}{I_{xx}^{\prime}}-\frac{I_{xx}^{\prime}}{I_{xx}^{\prime}}\right)$								
	28	.0347	+ 5wc	$+10\left(C_{n_{SW}}+\frac{I_{XX}}{I_{XX}}C_{SW}\right)$								
	29	.2725	-10 bre	$- \left(C^{u \otimes h} + \frac{I_{XX}}{I_{XX}} C^{\dagger \otimes h} \right) \qquad \qquad)$								
AMA	<i>3</i> 0	<u>9</u> ′00Γ0.		$+2(C_{n_{\beta}}+\frac{I_{NX}^{\prime}}{I_{NX}^{\prime}}C_{n_{\beta}})($ ")								
	31	.2700		$-\left(C_{n_{\dot{b}}}+\frac{\Gamma_{\dot{k}\dot{k}}}{\Gamma_{\dot{k}\dot{k}}}C_{\dot{b}\dot{b}}\right)(")$								
	32	.4000	-10R	$-\left(C_{R_{R}}+\frac{I_{XX}^{\prime}}{I_{XX}^{\prime}}C_{R_{R}}\right)\left('' \right)$								
	33	1191	+5\$	- Cys PSVo								
u l	34	.0384	-5P	+ Cyp PSVo								
ORC 23	35	.5052	+ IOR	+ .5 CYR PSVo +.5								
SIDE FORCE AMPL.23	36	<i>e</i> 710.	+ 6wc	-5 Cysw 2m								
511	37	.0150	-106rc	+.5 Cygr 2m								
, [38	.4076	- 2¢	+ 2.5 =								
AMPL.	39	.4000 ¹⁰	+.5P	SCALE FACTOR								

	SIMULATING: AMES LARGE TRANSPORT			367-8	30
	WEIGHT: 150 000 LBS) .		DEPEND: VARIABI	
	ALTITUDE: SEA LEVEL			9TRIM = 46.4	4
OF INTRTIA AXES	$I_{xx} = 2.57 \times 10^6$ 51.0	G FT	l	9 TRIMS = 130	,894
2 07 XX		G FT	2	THRUST _{TRIM} = 1	18,194 LBS
MOMENTS IN BODY	L P	G FT	2	MASS = 46	60 SLUGS
OZ Z	$I_{x\bar{x}} = .16 \times 10^6$ SLU	G FT	2	CLTRUM = 1.14	+6
FLIGHT	FLAP SETTING = 30° BLOWING PRESSURE RATIO = 1 SPEED BRAKE SETTING = 6 GEAR: DOWN			·	
RY	5 = 2821 FT2			DE SHAPES	
OMET RY	C = 20.1 FT b = 130.8 FT	SHC RJ9	1	ωυ =1.42 ωυ = 1.04 υ = 1.68	rad/sec rad/sec
GEO		PHUG	GIO:	$\omega_{0} = .157$ 751. = ω_{0} 3 = .0906	rad/sec rad/sec
TRIM	SPEED = 117 KTS (197.5 FT/SEC) CATRIM, BODY = 6.5° CATRIM, WING = 8.5°	DU T RO L	1		rad/sec rad/sec
	· · · · · · · · · · · · · · · · · · ·			181 = 1.584	
	•	ROLL		= 1.04	SEC
		SPIR DIVE		T.C. = 15.7 D.A. = -10.87	SEC SEC
CALC. CHECK APPD. APPD.	AIRPLI	HE BOEIR	DESC		PAGE A10

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A.L.T. MATRIX EQUATIONS

$$I'_{xx} = I_{xx} \cos^{2}\alpha + I_{zz} \sin^{2}\alpha - 2I_{xz} \sin\alpha\cos\alpha$$

$$I'_{xx} = 17.5 \times 10^{6} .99718 + (45 \times 10^{6})(.00212) - 2(.95 \times 10^{6})(.04706) = +17.4715 \times 10^{6}$$

$$I'_{zz} = I_{zz} \cos^{2}\alpha + I_{xx} \sin^{2}\alpha + 2I_{xz} \sin\alpha\cos\alpha$$

$$I'_{zz} = (45 \times 10^{6})(.99778) + (17.5 \times 10^{6})(.00222) + 2(.95 \times 10^{6})(.04706) = 45.0783 \times 10^{6}$$

$$I'_{xz} = (I_{xx} - I_{zz}) \sin\alpha\cos\alpha + I_{xz} (\cos^{2}\alpha - \sin^{2}\alpha)$$

$$I'_{xz} = (17.5 \times 10^{6} - 45 \times 10^{6})(.04706) + (.95 \times 10^{6})(.99778 - .00222) = -.3484 \times 10^{6}$$

$$I'_{xz} = \frac{-.3484 \times 10^{6}}{45.0769 \times 10^{6}} = -.00773$$

$$I'_{xz} = \frac{-.3484 \times 10^{6}}{117.4715 \times 10^{6}} = -.01994$$

CO = CTRIM, BODY = 2.7°

$$\frac{9.8b}{I_{xx}^{2} - \frac{I_{xx}^{2}}{I_{zz}^{2}}} = \frac{46.4 \times 5500 \times 215}{17.4715 \times 10^{6} - \frac{[-.3484 \times 10^{6})^{2}}{45.0283 \times 10^{6}}} = 3.1405$$

$$\frac{9.5b}{I_{ZZ}^{0} - \frac{I_{XZ}^{0}}{I_{XX}^{0}}} = \frac{54.868 \times 10^{6}}{45.0283 \times 10^{6} - \frac{112138 \times 10^{6}}{17.4715 \times 10^{6}}} = 1.2186$$

$$\frac{9.5}{10m} = \frac{46.4 \times 5500}{15,528} = 16.435$$

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	$I_{xx} = I_{xx} \cos^2 \alpha + I_{xx} \sin^2 \alpha - 2 I_{xx} \sin \alpha \cos \alpha$
	$I_{xx}' = (2.57 \times 10^{4})(98718) + (4.73 \times 10^{4})(20128) - 2(.16 \times 10^{4})(.1132)(.99357) = 2.5617x1$
	I'zz = Izz cos2 x + Ixx sin2 x + 2Ixz sinacosax
	$I_{ZZ} = (4.73 \times 10)(.98716) + (2.57 \times 10^6)(.0126) + (.03599 \times 10^6) = 4.7383 \times 10^6$
	$I_{xz} = (I_{xx} - I_{zz})$ Since cosoc + I_{xz} (cos ² α - sin ² α)
	$I_{XZ} = [2.57 \times 10^{4}] - (4.73 \times 10^{4}] - (10 \times 10^{4}) + (10 \times 10^{4}) + (10 \times 10^{4}) = -0.08704 \times 10^{-6}$ $I_{XZ} = -0.08704 \times 10^{4}$
L P.	$\frac{I_{XZ}'}{I_{ZZ}'} = \frac{06704 \times 10^6}{+ 4.7383 \times 10^6} =01836 \qquad \frac{I_{XZ}'}{I_{XX}'} = \frac{08704 \times 10^6}{+ 2.5617 \times 10^6} =034$
AIRPLANE	$\frac{9.5c}{1_{\text{IYY}}} = \frac{46.4 \times 2821 \times 20.1}{2.25 \times 10^6} = 1.169$
367 - BO	$\frac{9.5b}{I_{xx}^{2} - \frac{I_{xz}^{2}}{I_{zz}^{2}}} = \frac{46.4 \times 2821 \times 130.8}{2.5617 \times 10^{6} - \frac{(06704 \times 10^{6})^{2}}{4.7363 \times 10^{6}}} = 6.688$
κ.	$\frac{g_0 \text{Sb}}{I'_{zz}} = \frac{46.4 \times 2821 \times 130.8}{4.7383 \times 10^6 - \frac{7.576 \times 10^9}{2.5617 \times 10^6}} = 3.615$
	$\frac{g_0S}{lm} = \frac{46.4 \times 2821}{4660} = 28.089$
H J K * FINCH	$\frac{\frac{9.5\bar{c}}{T_{YY}}}{\frac{9.5\bar{c}}{T_{YY}}} = \frac{.2446}{1.169} = .2092$ $\frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{3.1405}{6.688} = .4696$ $\frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{10}{10} = \frac{3.1405}{6.688} = .4696$
LIFT, DRAG = TILL DRAG	$\frac{9.5}{0_{\text{m}}} \Big]_{\text{A.i.T.}} = \frac{16.435}{16.435} = 505 \ \text{K} = \frac{\frac{9.5 \text{ b}}{1/2}}{\frac{1}{22} - \frac{1/2}{1/2}} \Big]_{\text{A.i.T.}} = \frac{1.2186}{1.2186} = 337$

PITCH EQUATIONS

XAMPLE

MATRIX GAIN CALCULATIONS

$$\delta_{e_{DQ}} = \frac{K \left(C_{m_{QL}} \right)_{A.L.T.} - C_{m_{QL}-80}}{C_{m_{QL}-80}}$$

$$= \frac{.2092 \left(-2.07 \right) - \left(-1.10 \right)}{-.975} = \frac{-.4330 + 1.10}{-.975} = \frac{+.667}{-.975} = -.6841$$

$$\delta_{e_{\alpha}} = \frac{K(C_{m_{\alpha}})_{A.L.T.} - C_{m_{\alpha}-80}}{C_{m_{\alpha}-80}} = -.1599$$

$$\delta_{e_{Q}} = \frac{K(C_{m_{Q}})_{A.L.T.} - C_{m_{Q-80}}}{C_{m_{Se-80}}} = -.216$$

$$S_{e_{\Delta V}} = \frac{K(57.3 \times C_{m_{\Delta V}})_{A.L.T.} - C_{m_{\Delta V-80}}}{C_{m_{Se-80}}} = -.0438$$

$$\delta_{e_{\delta E}} = \frac{K (C_{m_{\delta E}})_{A.L.T.}}{C_{m_{\delta e-80}}} = +.3346$$

CONT'D.

PITCH EQUATIONS (CONT'D)

$$\delta_{e_{\Delta T-go}}$$
 = FUNCTION (See Page A2B)

$$\delta_{\text{ex}} + \delta_{\text{ex}} + \delta_{\text{ex}} + \delta_{\text{ex}}$$

$$\delta_{\text{ex}} = -.6841 \quad \Delta \propto -.1599 \quad \dot{\alpha} - .216 \quad Q -.0438 \quad \Delta N$$

$$+ \delta_{\text{ex}} + \delta_{\text{ex}-\text{so}} + \delta_{\text{e}} \delta_{\text{ab}}$$

$$+ .3346 \quad \delta_{\text{E}} + \text{function } \Delta T_{-80} + \text{function } \delta_{\text{abc}}$$

$$\frac{m_{-80}}{m_{A,L,T}} = \frac{4660}{15,528} = .300$$

$$\left(2\frac{9.5}{V_0}C_{0_{TRIM}}\right)_{-80} - \left(2\frac{9.5}{V_0}C_{0_{TRIM}} + 9.5C_{0_{N}}\right)_{A.L.T.} \frac{m_{-80}}{m_{A.L.T.}}$$

$$\Delta T_{-80_{AV}} = \left(2\frac{46A.282!}{197.5} \times .139\right)_{-80} - \left(2\frac{46.4.85500}{197.5} \times .450 + 0\right)_{A.L.T.} = -\frac{164.63}{197.5}$$

$$\Delta T_{-80} = \frac{m_{-80}}{m_{A.L.T.}} (1 - q_0 S C_{DAT})_{A.L.T.} = +.300$$

$$\Delta T_{-80} = q_0 S \frac{C_{0ab}}{57.3} = 0.0$$

$$\underline{\Delta T}_{\bullet \bullet \Delta \Delta} = \left(q_{\bullet} S \frac{c_{\bullet \alpha}}{57.3} \right)_{\bullet \bullet} \left[\left(q_{\bullet} S \frac{c_{\bullet \alpha}}{57.3} \right)_{A \perp T, \frac{m_{\bullet} g_{\bullet}}{4 \perp T}} \right] = -186.96$$

$$\Delta T_{80} = -164.63 \ \Delta V + .300 \ \Delta T_{ALT} + .0 \ \delta_{ab_c} - 186.96 \ \Delta C$$

$$\frac{\left(\frac{9.5}{b_{m}}C_{L_{\alpha}} + \frac{T_{o}}{m}\right)_{A.L.T.}\left(\frac{9.5}{b_{m}}C_{L_{\alpha}} + \frac{T_{o}}{m}\right)_{-80}}{\left(16.435 \times 6.81 + \frac{114.787}{15,528}\right)_{A.L.T.}\left(28.089 \times 5.418 + \frac{18.194}{4660}\right)_{-80}}{\left(28.089 \times -.808\right)_{-80}} = +1.62$$

$$\frac{\left(\frac{9.5}{b_{m}}C_{L_{Sab}}\right)_{-80}}{\left(\frac{9.5}{b_{m}}C_{L_{Sab}}\right)_{-80}}$$

$$\delta_{ab\dot{\alpha}} = \frac{\left(\frac{9.5}{10m}C_{L\dot{\alpha}}\right)_{A.L.T.}}{\left(\frac{9.5}{10m}C_{Lab}\right)_{-80}} = +.2866$$

$$\delta_{ab_{Q}} = \frac{\left(\frac{9.5}{8m}C_{L_{Q}}\right)_{AL.T}}{\left(\frac{9.5}{8m}C_{L_{ab}}\right)_{-90}} = -.5822$$

$$S_{ab} = \frac{\left(\frac{\alpha_o}{m}\right)_{A.L.T.} + 57.3 \left(\frac{9.5}{m}C_{LAT}\right)_{A.L.T.}}{\left(\frac{9.5}{m}C_{Lab}\right)_{-90}} = -.7659 \times 10^{-5}$$

$$S_{ab_{aT-80}} = \frac{-\left(\frac{\alpha_{o}}{m}\right)_{-80}}{\left(\frac{9 \cdot S}{m} C_{Lab}\right)_{-80}} = +8.037 \times 10^{-5}$$

$$\delta_{ab}\delta_{E} = \frac{\left(\frac{g_{o}S}{g_{m}}C_{L}\delta_{E}\right)_{A,L:T.}}{\left(\frac{g_{o}S}{g_{m}}C_{L}\delta_{b}\right)_{-g_{o}}} = -.2961$$

$$\delta_{ab}_{c} = 1.62$$
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 $\delta_{ab}_{ab} = 1.66$

ROLL EQUATIONS

MATRIX GAIN CALCULATIONS

$$\delta_{wg} = \frac{K \left(C_{fg} + \frac{I_{xz}^{'}}{I_{zz}^{'}} C_{ng} \right)_{A,L,T} \left(C_{fg} + \frac{I_{xz}^{'}}{I_{zz}^{'}} C_{ng} \right)_{-80}}{\left(C_{fg} + \frac{I_{xz}^{'}}{I_{zz}^{'}} C_{ng} \right)_{-80}}$$

$$= \frac{.4696 \left(-.1972\right) + .1760}{60.+} = \frac{-.0976 + .1760}{60.+} = \frac{+.0834}{60.+} = \frac{+1.391}{60.+}$$

$$S_{\omega_{p}} = \frac{K \left(C_{\ell_{p}} + \frac{I_{XZ}^{\prime}}{I_{ZZ}^{\prime}} C_{n_{p}}\right) - \left(C_{\ell_{p}} + \frac{I_{XZ}^{\prime}}{I_{ZZ}^{\prime}} C_{n_{p}}\right) - 80}{\left(C_{\ell_{S\omega}} + \frac{I_{XZ}^{\prime}}{I_{ZZ}^{\prime}} C_{n_{S\omega}}\right) - 80} = +.0776$$

$$\delta_{\omega_{R}} = \frac{K \left(C_{\ell_{R}} + \frac{I_{XZ}^{'}}{I_{ZZ}^{'}}C_{n_{\ell_{R}}}\right)_{A,L,T,} \left(C_{\ell_{R}} + \frac{I_{XZ}^{'}}{I_{ZZ}^{'}}C_{n_{R}}\right)_{-80}}{\left(C_{\ell_{S\omega}} + \frac{I_{XZ}^{'}}{I_{ZZ}^{'}}C_{n_{S\omega}}\right)_{-80}} = -.2186$$

$$\delta_{\omega} \delta_{w} = \frac{K \left(C g_{\delta w} + \frac{I_{XZ}^{\prime}}{I_{ZZ}^{\prime}} C_{\eta} S_{w} \right)_{A, L, T, L} \left(uo \ contribution \right)_{-80}}{\left(C g_{\delta w} + \frac{I_{XZ}^{\prime}}{I_{ZZ}^{\prime}} C_{\eta} S_{\omega} \right)_{-80}} = + .7623$$

$$\delta_{\omega S_R} = \frac{K \left(C \ell_{S_R} + \frac{I_{XZ}^*}{I_{ZZ}^*} C_{nS_N}\right)_{-\infty}}{\left(C \ell_{S_\omega} + \frac{I_{XZ}^*}{I_{ZZ}^*} C_{nS_\omega}\right)_{-\infty}} = +.0252$$

CONT'D.

ROLL EQUATIONS (CONT'D)

MATRIX GAIN CALCULATIONS

$$\delta_{\omega} \delta_{r} = \frac{K \left(w_{0} contribution\right)_{A,L,T,.}^{-} \left(C_{1} + \frac{I_{XE}^{\prime}}{I_{2E}^{\prime}} C_{n} S_{r}\right)_{-80}}{\left(C_{1} S_{\omega} + \frac{I_{XE}^{\prime}}{I_{2E}^{\prime}} C_{n} S_{\omega}\right)_{-80}} = -.2715$$

$$\delta_{\omega\dot{g}} = \frac{K \left(C_{1\dot{g}} + \frac{I_{xz}^{'xz}}{I_{zz}^{'zz}} C_{n\dot{g}}\right)_{a.l.T.} \left(C_{1\dot{g}} - \frac{I_{xz}^{'xz}}{I_{zz}^{'zz}} C_{n\dot{g}}\right)_{-60}}{\left(C_{1\dot{g}} + \frac{I_{xz}^{'xz}}{I_{zz}^{'zz}} C_{n\dot{g}}\right)_{-60}} = -.0305$$

YAW EQUATIONS

$$\delta_{r_{\delta}} = \frac{K \left(C_{n_{\delta}} + \frac{T_{xx}^{'}}{T_{xx}^{'}}C_{l_{\delta}}\right)_{n,t,t} \left(C_{n_{\delta}} + \frac{T_{xx}^{'}}{T_{xx}^{'}}C_{l_{\delta}}\right)_{-80}}{\left(C_{n_{\delta}r} + \frac{T_{xx}^{'}}{T_{xx}^{'}}C_{l_{\delta}r}\right)_{-80}} = +.2921$$

$$\delta_{rp} = \frac{K \left(C_{np} + \frac{I_{XZ}^{\prime}}{I_{XX}^{\prime}}C_{p}\right) - \left(C_{np} + \frac{I_{XZ}^{\prime}}{I_{XX}^{\prime}}C_{p}\right) - 80}{\left(C_{nSr} + \frac{I_{XZ}^{\prime}}{I_{XX}^{\prime}}C_{p}\right) - 80} = -.6096$$

$$S_{r_R} = \frac{K \left(C_{n_R} + \frac{I_{XX}'}{I_{XX}'} C_{\ell_R}\right)_{n, L, T} \left(C_{n_R} + \frac{I_{XX}'}{I_{XX}'} C_{\ell_R}\right)_{-80}}{\left(C_{n_{Sr}} + \frac{I_{XX}'}{I_{XX}'} C_{\ell_{Sr}}\right)_{-80}} = -.1610$$

$$\delta_{r_{SW}} = \frac{K \left(C_{n_{SW}} + \frac{1 \times 2}{1 \times x} C_{l_{SW}}\right)_{A \perp T} - \left(n_{0} contribution\right)_{-80}}{\left(C_{n_{Sr}} + \frac{1 \times 2}{1 \times x} C_{l_{Sr}}\right)_{-80}} = +.00911$$

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MATRIX GAIN CALCULATIONS

$$\delta_{rsg} = \frac{K \left(C_{nsg} + \frac{T_{xx}^{'}}{T_{xx}^{'}} C_{lsg} \right) - \left(no contribution \right)_{-80}}{\left(C_{nsg} + \frac{T_{xx}^{'}}{T_{xx}^{'}} C_{lsr} \right)_{-80}} = +.5366$$

$$\delta_{r_{Sw}} = \frac{K \left(w_{0} \cos r_{R} \cos r_{1} \cos w \right)_{ALT.}^{-} \left(C_{n_{Sw}} + \frac{I_{XX}^{2}}{I_{XX}^{2}} C_{1Sw} \right)_{-80}}{\left(C_{n_{Sr}} + \frac{I_{XB}^{2}}{I_{XX}^{2}} C_{1Sr} \right)_{-80}} = +.0128$$

$$S_{r_{\dot{\beta}}} = \frac{K \left(C_{n_{\dot{\beta}}} + \frac{I_{xx}^{'}}{I_{xx}^{'}} C_{l_{\dot{\beta}}}\right)_{n,l,T} \left(C_{n_{\dot{\beta}}} + \frac{I_{xx}^{'}}{I_{xx}^{'}} C_{l_{\dot{\beta}}}\right)_{-80}}{\left(C_{n_{\dot{\beta}}} + \frac{I_{xx}^{'}}{I_{xx}^{'}} C_{l_{\dot{\beta}}r}\right)_{-80}} = -1.1516$$

₽ 77_80	\mathcal{S}_{ab}	$\delta_{ m e}$	VARI	ABLE	გ _დ	δr
-186.96	+ 1.62	6841	Δα	₿	+ 1.391	+.2921
	+ .2866	1599	ά	\$	0 305	- 1.1516
	5822	216	Q	P	a FF0.+	6096
- 164.63	0	0438	M	R	2186	1610
+ .300	766×10 ⁻⁵	٥	ΔT _{A.L.T.}	8	£537. +	11600.+
	+ 8.037110"5		ΔT _{.80}	ح∞		+.0128
0		1323	Sab	δ_{R}	+.0252	+.5366
	2961	+ .3346	δ _E	δr	2715	

Example: if ; then the following equations apply

T-80	Sab	Se	·
+217	+2.1	63	8 00.
- 33	+.07	7.007	V4
+.25	-3110-6	+4.6 × 10 ⁸	ΔT_{SST}
_	+ 1.7:105	+2×104	ΔT-80
0	09	+.38	SE

ΔT-80 = 217 DOC - 33 DV +.25 ΔTA.LT

$$\delta_{ab} = 2.1 \Delta \alpha + .07 \Delta V - 3 \times 10^6 \Delta T_{A.L.T.}$$

+ 1.7 × 10 $\Delta T_{-80} - .09 \delta E$

6-70-10

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PAGE	1 Y Y 8 S 8	CDDE8 CLDV8 CMDT8	CLOWS CYRS CYPS	IYYS SS	CDDES CLOS CMDTS	CLDWS	1X2 PB					DABDTS	DEBOES	DWBDWS	DRBDWS	DCYDWS -
1.2090006 03	2.570000E 06 1.975000E 02	0. -2.720030E-01 -7.130000E-01	1.040000E-01 -1.790000E-02	1.750000E 07 1.975000E 02	0. -3.959000E-01 -5.550000E-01 -2.387000E 00	1.955000E-01. 9.050000E-02 -7.400000E-02	4.738313E 06		1.643488E 01	5.848990E-01	٥.	10-3649664.9	-4.384185E-02 D	-2.185805E-01 D	-1.610243E-01 D	-1.438144E-04 D
LADIAX	IXXB	CDDV8 CLDT8 CMAD8	CLR8 CNP8 CYBD8	IXXS	CDDVS CLADS CHADS CHOS	CLRS CNPS CYBOS	122P8 122PS	KDL SB	K DL SS	KDLS	DTBDAB	DABDEB	DE BDV DE BDFS	Q 80 8/	DR 8R	DC VR
1.000000E 02	1.919400E 04	0. 5.418000E 33 -1.103030E 00 -1.293009E-01	-1.200000E-01 -7.470000E-02 -8.380000E-01 2.110000E-01	1.147870E 05 4.640030E 01	0. 6.810000E 00 -2.07000E 00	-2.442300E-01 3.600300E-02 -9.773000E-01 2.464000E-31	2.561687E 06 1.747152E 07	3.615565E 00	1.218708E NO	3.370727E-01	3.000000E-01	-2.960689E-01 -5.822235E-31	-2.161574E-01 -1.323077E-01	7.761894E-32 5.994490E-02	-6.096087E-01	-4.199582E-03 -3.662373E-03
I. DNGAX	THTR8 QTR8	CDDT8 CLA8 CMA8	CLP8 CNB08 CYB8 CYDR8	THTRS	CDDTS CLAS CMAS	CYBS CYBS CYBS CYBS	LXXPB	KYAWS	KYAWS	KYAW	DTBDTS	DA.B.DES DABQ	DE 8Q DE 8 DA B	DW8P CLDWP8	DR8P CNDRP8	DCYP .
1.200000E 00	6.500000E DO 1.600000E DS 2.010000E D1	5.440000E-01 1.124200E 00 -8.080000E-01 -9.750000E-01	0. 9.090330E-32 T.490000E-02 -2.520000E-32	2.700000E 30 9.500000E 05 2.875000E 01	1.070000E 00 1.940000E 00 0. -1.560000E 00	2.180000E-04 2.180000E-01 -1.20000E-01 -3.660000E-02	9.935728E-01	6.687655E 00	3.140891E 00	4.696551E-01	-1.646347E 02	0. 2.865950E-31	-1.599184E-01	-3.047475E-02 -2.715111E-01	-1.151619E 00 1.275205E-02 (-7.553659E-04
AMESL T	ATR B IXZ8 C8	CDA8 CLT38 CLDAB CMDE8	CLBD8 CN38 CNDR8	ATRS 1X2S CS	CDAS CLTAS CLDFS CLDFS	CABDS CABS CADRS CYDAS	COSAB	KROLB	KROL S	KRDLL	DTBDV	DABDV	DE 9 A D	DW863 DW80R8	DR 890 DR 8948	0CY30 0CY3#8
1.109650E 01	1.500000E 05 4.730000E 06 1.308000E 02	1.390000E-01 D. 5.200000E-01 -7.460000E-04	-1.743700E-01 1.492300E-02 3.009000E-03 7.270300E-02	5.00000E 05 4.50000E 07 2.15000E 02	4.500000E-01 0. 4.090000E-01 0.	-1.955000E-01 2.290000E-03 -10.001000E-05 1.105000E-01	1.131949E-01 4.710299E-02	1.169323E 00	2.445667E-01	2, 091523E-01	-1.869572E 02	1.622218E 00 8.036862F-05	-6.841587E-01	1.390618F 00 2.521003E-02 [2.921084E-01 5.366150E-01	4.648835E-03 2.515168E-03 D
DATE	MG8 1228 B8	CDTR8 CDDAB CLDE8 CMDV8	CLBB CLDRB CNDWB CYRB	MGS 1225 BS	COTRS CODES CLDES CMDVS	CL DRS CND#S CYRS	SINAB	KP 1 18	KPITS	KPJJCH	DT 80 A	DABDA DABDT 8	DE 8DA DE 8DT S	DWRB DWBORS	DR 80R S	DCYB CCYDRS

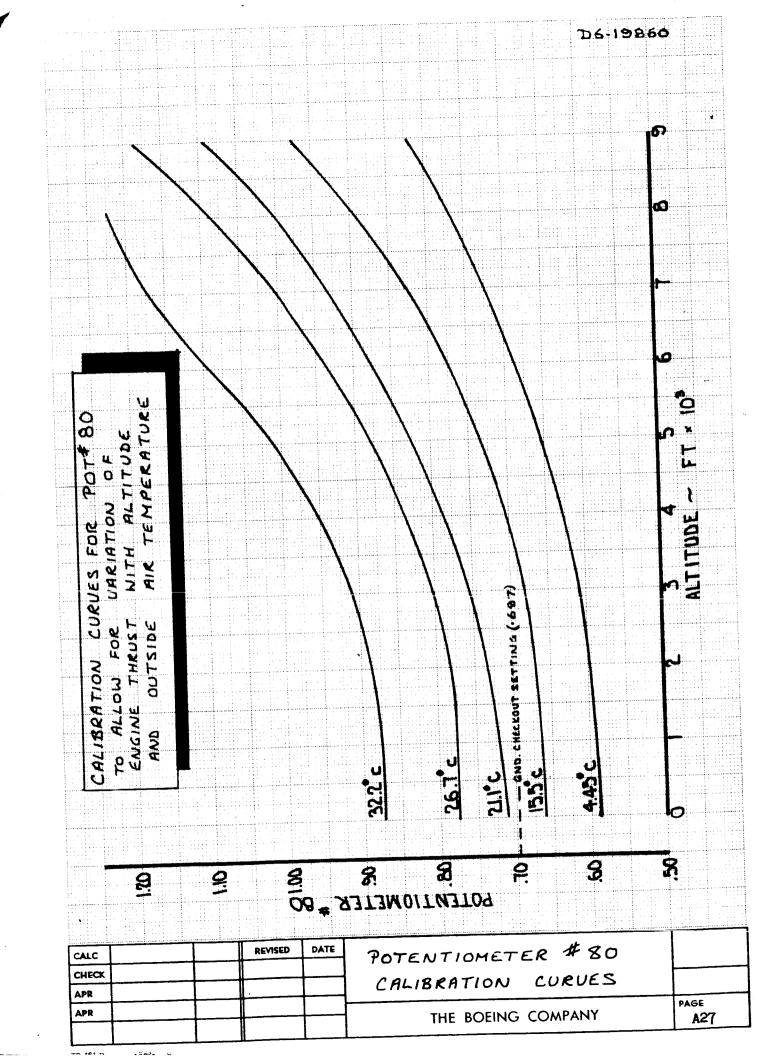
AD 48726

1.1096506		6	7 AME SLT	LONG. COA	1F/G.	#100 (8#51C)	(C)	LAT. CONFIG.	ONF.	6.# 1209(BASIC,	(38 SIC)	
.000000E 00 .000000E-01 .000000E-03 K	0100	× 55	A X A S	. 000000E . 000000E . 000000E	1	8888	K B B C K D W B K D W S	5 88	KOR 8	:	1	
-1.865572F 02 DT8DV	20	0 1	AQ	-1.646347E 02	DYBDTS	3.000000E-01	DYBDAB	0.				
1.622218E 00 DABDV 8.036862E-05 DABAD	80	DAG	≥ 04	0. 2.865860E-01	DABDES	-2.960689E-01	DABDER	6.435643E-01 DABDTS	1 ;	-7.658660E-06		
-6.841587E-01 DE 8AD	6	0E (35	-1.599184E-01	DEBO	-2.161574E-01 -1.323077E-01	DEBDY	-4.384185E-02 DE8	BDE S	3.346437E-01		
1.390618E ON DWBBD 2.521003F-02 DWBDRB	00-	DAG	88	-3.047475E-02 -2.715111E-01	DV8P	7.7618948-02	DWSR	-Z.185803E-01 DW6DWS	SMQ	7.62330ZE-01	;	
2.921084E-01 DR 5.368150E-01 DRB	D. R.	~ •	980	-1.151619E On	DABP	-6.096087E-01	DRBR	-1.610243E-01 DR8	80 # S	9.112884E-03		
1.679143F-01 1.134826F 00 7.183666F-01 2.301697F-01	000	· .									· · · · · · · · · · · · · · · · · · ·	
0.946154E-02 1.736879F 00			!		:							
1.869572F-01 1.500000E 00 8.231735E-01	100						1					
0.			:						;			
0. 1.607372F-01	5 5											
10 ,	ł 1						:	:	,			
5-872206 UU	1			a de la desta de la desta de la dela della			!	4	, ,			
4.371610E-01 3.104750E-01 5.562472E-01	10-										;	
1.524660E 00 5.042006E-02 5.430222E-02	-02								İ		; !	
1.151619E 00 1.219217E 01 1.610243E 00	00 00	<u> </u>						1				
5.842168E-01 4.633E50E 00 9.112884E-02 6.376025E-02	-02											
		ļ	í									

	MA	ES L	ARGE TRAI	NSPORT ~ LONGITUDINAL
PO- NO.	TENTIOMET SETTING	ER TO	VARIABLE	CALCULATED FROM
62 64 65 66 67 68 70	.7620 .1679 .1135 ²⁹ .7184 .7284 .1800 .1757 ¹⁹	A44 A43 A43 A43 A44 A44	- 502 + Q + 5002 + DV - 5 Scian + DE	- $\delta_{e_{ac}}$ (1.05) = -(1599) × 1.05 = .1679 - $\delta_{e_{ac}}$ (1.05 × 5) = -(216) × 5.25 = 1.135 - $\delta_{e_{ac}}$ (1.05) = -(6841) × 1.05 = .7183 - $\delta_{e_{ac}}$ (1.05 × 5) =0438 × 5.25 = .2302 function $\delta_{e_{at-60}}$ compensation + $\delta_{e_{be}}$ (1.05 × 5) = .3346 × 5.25 = 1.757
72 73 74 76	.1877 .150 ¹² .8238	A46	001AT _{ALI} + ΔV +	$-\Delta T_{\Delta \infty}(.001) = -(-186.96)(.001) = .1870$ $+ \Delta T_{\Delta T_{AT_{AL}}}(5) = .300 \times 5 = 1.50$ $-\Delta T_{\Delta T_{A}}(.005) = -(-164.63)(.005) = .8232$ $-\Delta T_{\delta_{ab}}(.0005) = 0.0$
90	.697	AGZ	005ΔT _{-so}	+ $\frac{S_{th}}{\Delta T_{-80}}$ (600) = $\frac{600}{861}$ = .697 861 based on $\frac{\Delta T}{960}$ = 1080
79 81 82 83 85 85	.5732 .1656 .0766 .2961 ¹⁹ .3244 ¹⁹ .5822 ¹⁹	A47 A48	001AT _{ALT.} + S _E + 5DX	+ $\delta_{ab_{at}}(2) = .2866 \times 2 = .5732$ + $\delta_{ab_{at-a}}(2000) = (8.04 \times 10^{5})(2 \times 10^{5}) = .1607$
	NO. 62 64 65 66 76 72 73 74 76 90 79 80 85 85 85 85 85 85 85 85	POTENTIOMET NO. SETTING 62 .2620 64 .1679 65 .1135 ¹² 66 .7184 67 .7284 68 .1800 70 .1757 ¹² 71 .1000 72 .1877 73 .150 ¹² 74 .8238 76 0 90 .697 79 .5732 61 .1656 82 .0766 83 .2961 ¹² 85 .3244 ¹²	POTENTIOMETER NO. SETTING TO 62 .2620 A44 64 .1679 A44 65 .1135 PA43 66 .7184 A43 67 .7284 A43 68 .1800 A44 70 .1757 PA44 71 .1000 A49 72 .1877 A46 73 .150 PA4 74 .8238 76 0 90 .697 AG2 79 .5732 A47 81 .1656 A47 82 .0766 A48 83 .2961 A48 85 .3244 PA8	POTENTIOMETER VARIABLE NO. SETTING TO 62 .2620 A44 + 20 be rain 64 .1679 A44 - 5 ic 65 .1135 10 A43 + Q 66 .7184 A43 + 5Noc 67 .1284 A43 + N 68 .1800 A44 .5 be lam 70 .1757 10 A44 + BE 71 .1000 A49 + 10 be lec 72 .1877 A46 + 5Noc 73 .150 10 001 ATall 001 ATall 74 .8238 + AV + 10 be lec 76 0 + 10 be lec 001 ATall 79 .5732 A47 -5ix 81 .1656 A47 005 ATes 82 .0766 A48 001 ATall 83 .2961 10 A47 + be 85 .3244 10 A48 + 5000

		14	NES L	ARGE TR	ANSPORT ~ LATERAL
	POT	ENTIOMETE	R	VARIABLE	CALCULATED FROM
	NO.	SETTING	70	VARIABLL	CALCOLATED TROM
	106	.0061	A82	-ıob	$-8_{\omega_{\hat{\bullet}}}$ (.2) = -(0305)(.2) = .0061
	107	.4400	A82	- <i>B</i>	-8_{ω_R} (2) = -(2186)(2) = .4372
	108	.3105	28A		$+ \delta_{\omega_p} (4) = .0776 \times 4 = .3105$
	111	.5562 ^{.<u>\$</u>}	18A	- 5B	$+ 6_{\omega_8} (.2) = 1.391 \times .2 = .2782$
긤	112	.1525 ²	IBA	- 8 _₩	+ 606m = .7623
ROLL	114	. 0504	28A	+ 6R	+ 6ws (2) = .0252 x 2 = .0504
	115	.0543 ^{.5}	18A	+108rc	- Swsr (.1) = - (2715) × .1 = .0272
	117	.005 ^{.5}	184	-108 RRISE	+ Euse (.1)= .0252 × .1 = .0025
					BALL CANTON EFFECTIVENESS
	84		TROOK 97		ROLL CONTROL EFFECTIVENESS
	118	. 1152 ^{<u>19</u>}		-10B	
			EGA	-10B +.5P	$-\delta_{r_{\hat{a}}} = -(-1.1516) = 1.1516$
	118	.6105 <mark>20</mark>	A63 A84	+.5P	$-\delta_{r_{\hat{\theta}}} = -(-1.1516) = 1.1516$ $-\delta_{r_{\hat{p}}} (20) = -(6096) \times 20 = 12.19$
	811 119	.6105 <mark>20</mark> .1610 ¹⁹	A63 A64 A63	+.5P	$-\delta_{r_{\hat{a}}} = -(-1.1516) = 1.1516$
	118 119 120 121	.6105 <mark>20</mark> .1610 ²⁰	A63 A64 A63	+.5P - R -5B	$-\delta_{r_{\hat{\theta}}} = -(-1.1516) = 1.1516$ $-\delta_{r_{\hat{\theta}}} = (20) = -(60\%) \times 20 = 12.19$ $-\delta_{r_{\hat{\theta}}} (20) = -(1610) \times 10 = 1.610$ $+\delta_{r_{\hat{\theta}}} (2) = .2921 \times 2 = .5842$ $-\left[\delta_{r_{\hat{\theta}}} (10) - 10\right] = -\left[(.5366)(10) - 10\right] = 4.634$
ZAM	118 119 120 121	.6105 <u>2</u> .1610 <u>12</u> .5852	A63 A84 A63 A84	+.5P - R -5B + 8r +8w	$-\delta_{r_{R}} = -(-1.1516) = 1.1516$ $-\delta_{r_{P}} (20) = -(60\%) \times 20 = 12.19$ $-\delta_{r_{R}} (10) = -(1610) \times 10 = 1.610$ $+\delta_{r_{B}} (2) = .2921 \times 2 = .5842$ $-\left[\delta_{r_{SR}} (10) - 10\right] = -\left[(.5366)(10) - 10\right] = 4.634$ $+\delta_{r_{SM}} (10) = .0091 \times 10 = .091$
YAN.	811 19 120 121 121	. 6105 ²² . 1610 ¹² . 5852 . 46 34¹²	A63 A64 A63 A64 A64	+.5P - R -5B + 8R + 8w + 8w	$-\delta_{r_{\dot{\theta}}} = -(-1.1516) = 1.1516$ $-\delta_{r_{\dot{\theta}}} = -(-1.1516) = 1.1516$ $-\delta_{r_{\dot{\theta}}} (20) = -(-60\%) \times 20 = 12.19$ $-\delta_{r_{\dot{\theta}}} (10) = -(-1610) \times 10 = 1.610$ $+\delta_{r_{\dot{\theta}}} (2) = .2921 \times 2 = .5842$ $-\left[\delta_{r_{\dot{\theta}}} (10) - 10\right] = -\left[(.5366)(0) - 10\right] = 4.634$ $+\delta_{r_{\dot{\theta}}} (10) = .0128 \times 10 = .128$
NAY.	118 119 120 121 122 123	.6105 ²² .1610 ¹² .5852 .46 34¹² .0911	A63 A84 A83 A84 A84 A83	+.5P - R -5B + 8R + 8W + 8Wc	$-\delta_{r_{B}} = -(-1.1516) = 1.1516$ $-\delta_{r_{P}} (20) = -(60\%) \times 20 = 12.19$ $-\delta_{r_{P}} (10) = -(1610) \times 10 = 1.610$ $+\delta_{r_{B}} (2) = .2921 \times 2 = .5842$ $-\left[\delta_{r_{SR}} (10) - 10\right] = -\left[(.5366)(10) - 10\right] = 4.634$ $+\delta_{r_{SW}} (10) = .0091 \times 10 = .091$ $+\delta_{r_{SW}} (10) = .0128 \times 10 = .128$
NAY.	118 119 120 121 122 123 124	.6105 ²² .1610 ¹² .5852 .46 34¹² .0911	A63 A84 A83 A84 A84 A83	+.5P - R -5B + 8R + 8w + 8w	$-\delta_{r_{\dot{\theta}}} = -(-1.1516) = 1.1516$ $-\delta_{r_{\dot{\theta}}} = -(-1.1516) = 1.1516$ $-\delta_{r_{\dot{\theta}}} (20) = -(-60\%) \times 20 = 12.19$ $-\delta_{r_{\dot{\theta}}} (10) = -(-1610) \times 10 = 1.610$ $+\delta_{r_{\dot{\theta}}} (2) = .2921 \times 2 = .5842$ $-\left[\delta_{r_{\dot{\theta}}} (10) - 10\right] = -\left[(.5366)(0) - 10\right] = 4.634$ $+\delta_{r_{\dot{\theta}}} (10) = .0128 \times 10 = .128$

POT.	SETTING		POT.	SETTING		POT.	SETTING		
1 2 3 4 5	.3333		51 52 53 54 55 56	.1124 .2595 0.0 .0150 .2272		101 102 103 104 105 106	.4468 .1843 .1841 .0184 .1861		
7 8 9	.1000 <u>10</u> .1000 <u>10</u> .2740	1	57 58 59	.0634 .8273		107 108 109	.4372 .3105 .8150		
10 11 12	.8000	·	60 61 62	.5000 .5300 .1845 .2620		110 111 112	.0500 .5562 <u>.5</u> .1525 <u>5</u>	_	
13 14 15	.8000 .530 <u>20</u> .2961 <u>10</u> .7700		63 64 65	.6957 .1679 .1135		113 114	. 2660 (d	dial) $\delta_{\mathbf{w}}$	limit
16 17 18	.1845 .2961		66 67 68	.7184		115 116 117	.0543.5 .2660 (c	dial) δ_{w}	limit
19 20			69 70	.175710		118 119 120	.0050:2 .1152:10 .6096:10 .1610:10		
21 22 23	.1177 ¹⁰ .0544 .2005		71 72 73	.1877 .1500	1	121 122 123	.1610 <u>10</u> .5842 .4634 <u>10</u> .0911		
24 25 26	. 354 5 . 8000		74 75 76	.823 8 .2500 0.0		124 125	.1280 .5366		
27 28 29	.1000 .0347 .2725 .0700		77 78 79	+40V lim	it on A52 (.255 dial)		
30 31 32	.0700 .2700 .4000		80 81 82	.1656 .0766					
33 34 35	.1191 .0384 .5052		83 84 85	.3244 ¹⁰					
36 37 38	.0179 .0150		86 87 88	.4150 (.3000 .582210	dial) b li	mit			
39 40	.4076 ₁₀ .4000 .0500		89 90	.4150 (d	dial) & w lis	mit			
41 42 43	.1600 .0704 .0128		91 92 93	.0166 .1627 .4610					
44 45 46	.0575 .7900 .4679		94 95 96	.1633 .2263 .9229					;
47 48 49	.0597 .0395 .0533		97 98 99	.9046 .3252 .1875			-		
50	0.0		100	.3767		AMES I	ARGE T	RANSPO	RT
						BASIC T	OT. SET	LIST	



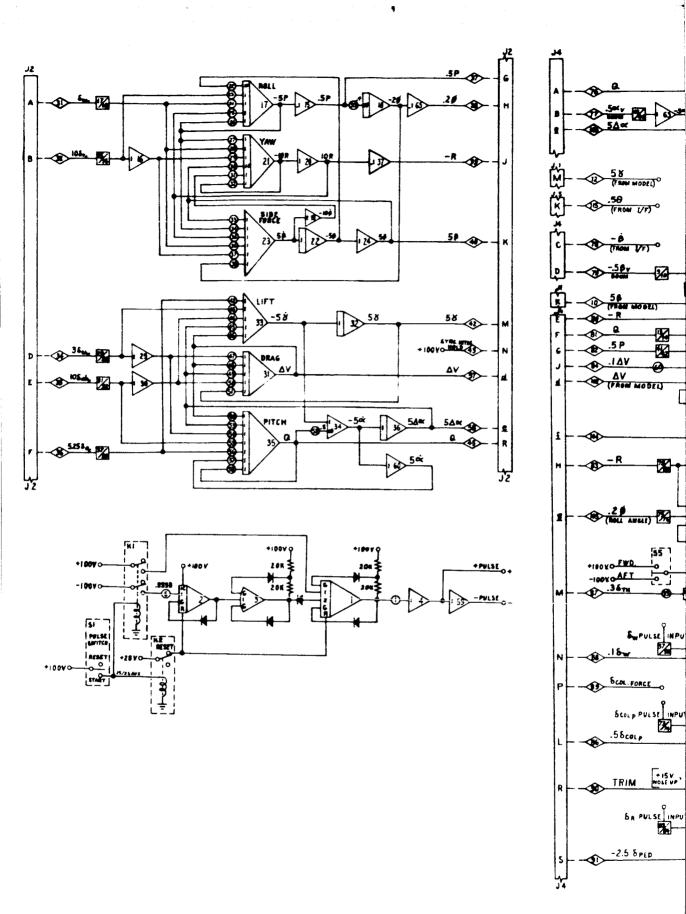
16-18860 (S470A) #1# 2/3 200200 20. -/00 INPUT TO FIG#14 (VOLTS) CLANSHELL DOOR EQUIN CALC REVISED DATE FUNCTION F/G # 14 CURVE FOR CHECK COMPENSATION FOR NON-LINEAR APR PITCHING MOMENT WITH THRUST. APR THE BOEING COMPANY PAGE A28 TD 461 C-R4

D6-19860 0 8 RESOLTS BROM TEST FLIGHT O duteul ERPH FAMS (VOLTS) 12 9 INPUT TO FIL#9 EQUIN SPOILER CALC REVISED DATE FUNCTION CURUE F/G # 9 FOR CHECK COMPENSATION FOR NON-LINEAR APR PITCHING MOMENT WITH SPOILERS APR THE BOEING COMPANY PAGE A29 TD 461 C-R4

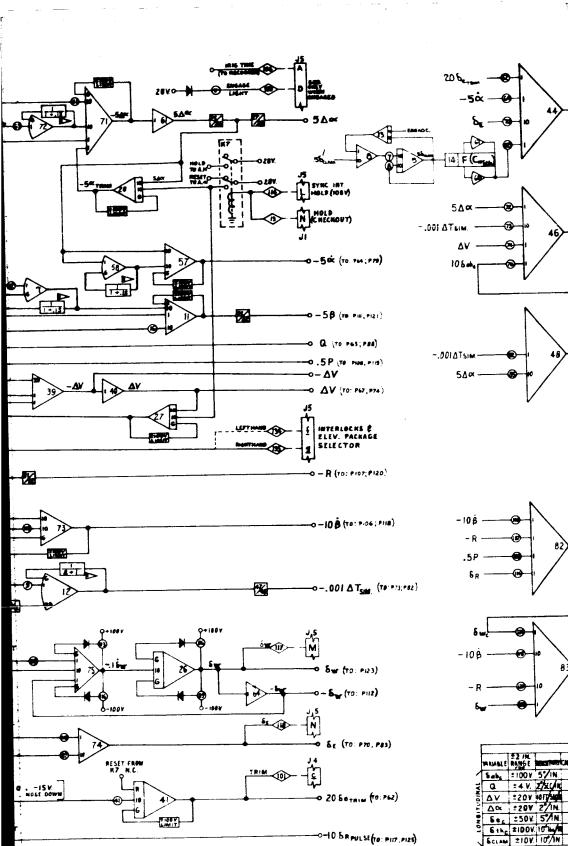
				AMES	0007
			LAR	GE TRANS	PORT
	WEIGHT: 500,000 LBS C.G. LOCATION: 25 c			DEPENDE VARIABL	
	ALTITUDE: SEA LEVEL			9TRIM = 46A	PSF
MOMENTS OF INERTIA IN BODY AXES	$I_{YY_8} = 30 \times 10^6$ SLU $I_{ZZ_8} = 45 \times 10^6$ SLU	G FT G FT G FT	-2 ·2	$Q_{TRIM} 5 = 255,10$ $THRUST_{RIM} 114,10$ $MASS = 15,526$ $\frac{Ixx_B}{qSb} = .3186$	787 LB5 22012 6
FLIGHT	FLAP SETTING: LANDING COMENGINE TIME CONSTANT: GEAR: DOWN AT = 3,180LB/DEG (THR	SEC		Tyre = 4.089	SEC2
\$	5 = 5500 FT ²		MOD	E SHAPES	
EOMETRY	c = 28.75 FT	ł	ORT NOD	ω _υ = .939 ω _{υ =} .644 J = .728	RAD/SEC RAD/SEC
GE	b = 215 FT	PHU	GOID	$\omega_0 = .176$ $\omega_0 = .174$ J = .139	rad/sec rad/sec
Σ	SPEED = 117 KTS (1975 FT/SEC) CTRIM, BODY = 2.7°	יטס	TCH	$\omega_0 = .508$ $\omega_0 = .479$	RAD/SEC RAD/SEC
TRIM	STABILIZER TRIM RATE = .44 DEG	RO	LL	β = .329 <mark> φ </mark> = 1.33 β	
	$\delta = 0.0 DEG.$	ROLL	_ T.C.	= 1.14	SEC
		1	ERG.	T.C. =26.5 D.A =-18.3	SEC SEC
CALC. CHECK APPD. APPD.	AIRPL	ANE		BILITY CRIPTION	PAGE
			NTON, WAS		A30

	CONTROL	CONTROL & STABILITY DERIVATIVES			
	DRAG	C _{DTRIM} Coa C _{DSE}	.45 .07 062	DAS\ CAS\	
CONFIG 100 (BASIC) —	LIFT	Cu _{trim} Cua Cuia Cua Cuge	1.94 6.81 3959 .8043 .409	/RAD /RAD/SEC /RAD/SEC /RAD	
NO3 ————	PITCH	Cma Cma Cma Cmse	-2.07 555 -2.387 -1.56	/RAD /RAD/SEC /RAD/SEC /RAD	
1	(STABILIZER)	Cmgs	0545	<i>∕</i> R <i>AD</i>	
	ROLL	Clb Clb Clp Clk Clbw Clbr	1955 00069 2442 .1955 .0973	/RAD/SEC /RAD/SEC /RAD/SEC /RAD/SEC /RAD /RAD	
CONFIG 1209 (BASIC)	WAY	Cns Cns Cnp Cns Cnsw Cnse	.218 .036 .0905 2883 0001 12	/RAD/SEC /RAD/SEC /RAD/SEC /RAD/SEC /RAD /RAD	
	SIDE FORCE	Cys Cys Cys Cysw Cysr Cysr	9773 074 .06 .1105 0366 .2464	/RAD /RAD/SEC /RAD/SEC /RAD/SEC /RAD /RAD /RAD	

A30-2



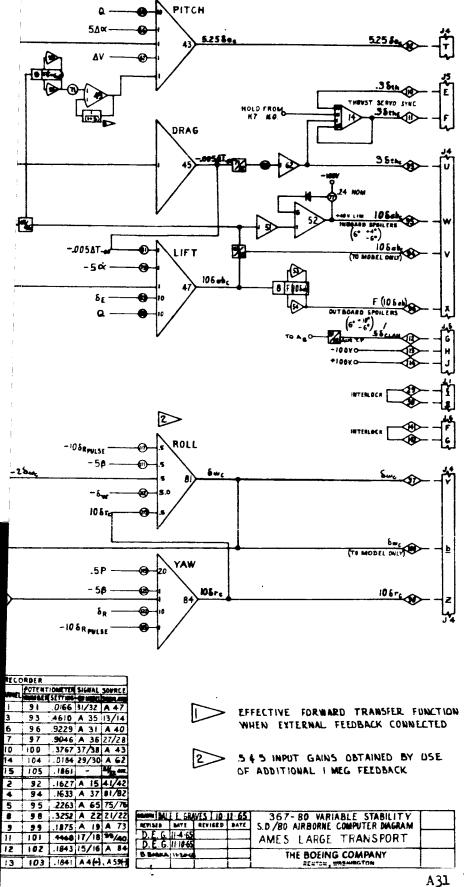
A31-1



A31-2

±IDV 5/SEC

O BR (10: PH4; PRZ)



SHEET BL

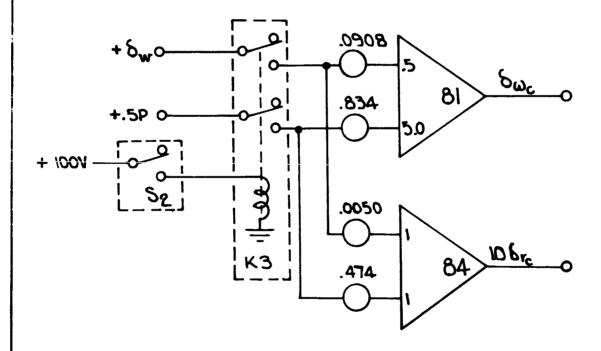
APPENDIX B AMES LARGE TRANSPORT VARIATIONS

1.0 CALCULATIONS AND CORRESPONDING AUXILIARY CIRCUITS AND POTENTIOMETER CHANGES.

1.1 LATERAL-DIRECTIONAL VARIATIONS

The Lateral-Directional variations were all obtained by changing potentiometer settings except for Configuration 1235 which employed an auxiliary circuit. This circuit, shown below, enabled additional inputs from δ_{W} and P to be switched into Amplifiers 81 and 84. Since the basic connections of δ_{W} and P into Amplifiers 81 and 84 were permanent, the auxiliary potentiometer settings were calculated to provide the difference necessary to make the required changes.

AUXILIARY CIRCUIT FOR CONFIGURATION 1235



The details of the other changes necessary to implement the Lateral-Directional variations follow:

a) Maximum Wheel Command and Maximum Wheel Rate

These maximum values were obtained by electrical limits on the wheel command input circuit. The maximum values were set by

APPENDIX B (Continued)

a) changing the appropriate potentiometers (Pll3 and Pll6 for maximum wheel rate and P86 and P89 for maximum wheel command) to achieve the required voltage limit on the relevant amplifiers. The following table illustrates these changes:

CONFIG.	REQUIRED SWMAX.	CORRESPONDING VOLTAGE LIMIT AMP #75	SETTING FOR POTS 113 & 116	REQUIRED δ _W MAX.	CORRESPONDING VOLTAGE LIMIT AMP #26	SETTING FOR POTS 86 & 89
1209 Basic	375 %sec.	37.5 v	.266 (Dia1)	75°	75 V	.415 (Dial)
1203 A	150° "	15.0 "	.122 "	30°	30 "	.231 "
1207 A	150° "	15.0 "	.122 "	30°	30 "	.231 "
1235	250° "	25.0 "	.20 "	50°	50 "	.30 "
1237	66° "	6.6 "	.062 "	50°	50 "	.30 "

b) Wheel Sensitivity

The changes in wheel sensitivity were obtained by changing the value of the control derivative C for the A.L.T. configuration.

The new values were supplied by NASA personnel and implemented in the simulation by recalculating the corresponding values of $b_{\omega_{c}}$

It was also necessary to change the values of δt_{char} to maintain $C_{N_{DW}}$ for the simulated airplane at 0.

These new values were obtained from the BLITZ Program and resulted in the following A.L.T. Matrix Potentiometer settings:

CONFIG.	REQUIRED Cℓ _{SW}	CORRESPONDING POT. SETTINGS		
NO.	°0W	P 112	P 123	
1209		Smer	Srsw	
BASIC	.0973	.1525	.0911	
1203A	.1457	.2283	.1342	
1207A	.0912	.1429	.0857	
1235	.0915	.1525 .091*	.0911 .0052#	
1237	.0915	.1434	.086	

* Auxiliary Potentiometer settings

APPENDIX B (Continued)

b) Wheel Sensitivity (Continued)

The auxiliary potentiometer settings are calculated as follows:

i) $\omega_{\text{SW}}(\text{Basic}) = .7623$

 $S_{\omega} \subseteq (1235) = .7169$

difference = $S_{\omega S_{M}}(1235)$ - $S_{\omega S_{M}}(Basic)$ = -.0454.

The output scaling is $1 \delta_{kl}$ and the input is $1 \delta_{kl}$.

- . . The auxiliary potentiometer setting = .0454
- = .0908 into a gain of .5 on Amp A81.
- ii) $\delta r_{\delta W}(Basic) = .0091$

 $6r_{\text{c...}}(1235) = .0086$

difference = $\delta_{r_{SW}}$ (1235) - $\delta_{r_{SW}}$ (Basic) = -.0005.

The output scaling is 10 or and the input is 1 ow.

... The auxiliary potentiometer setting = .0005 x 10 = .005

into a gain of 1 on Amp A84.

c) Roll Time Constant

The change in roll time constant was obtained by changing the value of C_{ℓ_D} and C_{ℓ_D} for Configuration 1235.

The new value of $\mathcal{C}_{\ell p}$ was supplied by NASA and the corresponding A.L.T. Matrix gain for $\mathcal{S}_{\omega p}$ obtained from the BLITZ Program. This new value was implemented in the simulation by means of the auxiliary circuit described previously which provided additional inputs from P to amplifiers A81 and A84.

The new values of $\delta\omega_P$ and δr_P were obtained from the BLITZ Program and the auxiliary potentiometer settings calculated as follows:

i) $\delta\omega_{\rm P}({\rm Basic}) = .0776$

 $\delta\omega_{\rm p}(1235)$ = -2.000

difference = $\delta \omega_P(1235) - \delta \omega_P(Basic) = -2.0776$.

The output scaling is 18ω and the input is .5P.

- . . Auxiliary potentiometer setting = $\frac{2.0776}{.5 \times 5}$
- = .834 into a gain of 5 on Amp A81.

6: 45774.

45 457/

APPENDIX B (Continued)

- c) Roll Time Constant (Continued)
 - ii) $\delta r_{p}(Basic) = -.6096$ $\delta_{r_{p}}(1235) = -.6333$ difference = $\delta r_{p}(1235) \delta r_{p}(Basic) = -.0237$.
 The output scaling is 10 δr and the input is .5P.

 .'. Auxiliary potentiometer setting = $.0237 \times 10$ $\frac{.0237 \times 10}{.5}$

= .474 into a gain of 1 on Amp A84.

APPENDIX B (Continued)

1.2 LONGITUDINAL VARIATIONS

The longitudinal variations were implemented with a combination of basic potentiometer changes and auxiliary circuits. The variations involved changes in the values of C_{LSE} , $\delta_{E/S_{COL}}$, C_{MSE} , C_{MSE} , and C_{MQ} as shown in Table II, Page 58.

The new values for these derivatives were supplied by MASA and implemented in the following manner:

- a) Elevator to Column Gearing $(\delta \varepsilon/\delta_{COL})$. The three values of $\delta \varepsilon/\delta_{COL}$ simulated were 1.5, 3.0 and 4.5. These changes involved a simple gain change and, since the scaling of δ_{COL} was .5 δ_{COL} , were obtained by setting potentiometer P87 in the basic patching to .3000, .6000, and .9000, respectively, into a gain of 10 on Amp A74.
- b) Lift Coefficient Due to Elevator $(C_L s_E)$ The values of $C_{L} s_E$ simulated were +.40, 0, and -.40.

The basic value of .40 resulted in an input of $\delta \epsilon$ through potentiometer P83 set at .2961 into a gain of 10 on Amp A47.

The C_{LSE} of 0 was obtained by switching in an input from SE through an auxiliary potentiometer also set at .2961 into a gain of 10 on Amp A48. This had the effect of cancelling out the basic value.

The C_{LSE} of -.40 was obtained by switching in an additional input of SE through another auxiliary potentiometer set at .2961 into a gain of 10 on Amp A48.

c) Elevator Power (Cm &)
Two values of Cm & were simulated; -1.56 which was the basic value, and -2.3.

The value of -2.3 was obtained by switching in an additional input of $\delta \epsilon$ through an auxiliary potentiometer into Amp A44 to make up the difference. The setting of the auxiliary potentiometer was obtained as follows:

$$\delta \epsilon \delta_{\epsilon} (C_{m} \delta_{\epsilon} = -1.56) = .3346$$
 from BLITZ

difference = .4827 - .3346 = .1481 Output scaling is 5.25 δ_e and the input is δ_e

... Auxiliary potentiometer setting = .1481 x 5.25 = .7971 into a gain of 1 on Amp A44.

APPENDIX B (Continued)

1.2 LONGITUDINAL VARIATIONS (Continued)

- Pitching Moment Coefficient Due to Angle of Attack (CMQ)

 Three values of CMQ were simulated; -2.C which was the basic value, -4.0 and -0.5. The CMQ of -4.0 was obtained by switching an additional input into Amp A43 through an auxiliary potentiometer and the CMQ of -0.5 by switching an additional input into Amp A44 through an auxiliary potentiometer. The auxiliary potentiometer settings were calculated as follows:
 - i) δεΔα(Cmα = -2.0) = -.6842 from BLITZ
 δεΔα(Cmα = -4.0) = -.2701 from BLITZ
 difference = -2701 + .6842 = +.4141
 Output scaling is 5.25 δε and input is -5Δα
 . Auxiliary potentiometer setting = (4141 x 5.25)/5
 into a gain of 10 on Amp A43.
 - SeΔα(Cmα = -2.0) = -.6842 from BLITZ
 SeΔα(Cmα = -0.5) = -1.0209 from BLITZ
 difference = -1.0209 + .6842 = -3367
 Output scaling is 5.25 δε and input is -5Δα
 ... Auxiliary potentiometer setting = ·3367 x 5.25 / 5
 into a gain of 10 on Amp A44.
- e) Pitching Moment Coefficient Due to Pitch Rate (CmQ)
 Two values of CmQ were simulated; -2.4 which was the basic value, and -4.8

The C_{MQ} of -4.8 was obtained by switching an additional input from Q into Amp A44 through an auxiliary potentiometer. The setting of this potentiometer was calculated from:

$$\delta_{e_Q}(C_{m_Q} = -2.4) = -.2162$$
 from BLITZ $\delta_{e_Q}(C_{m_Q} = -4.8) = .3015$ from BLITZ

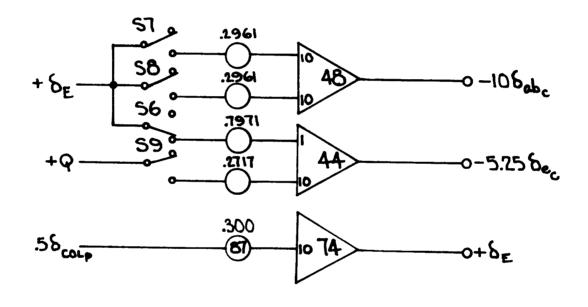
difference = .3015 + .2162 = .5187 Output scaling is 5.25 Se and input is Q

... Auxiliary potentiometer setting = $.5187 \times 5.25 = .2718$ into a gain of 10 on Amp A44.

The following figures show the two auxiliary circuits as they were set up to effect these changes:

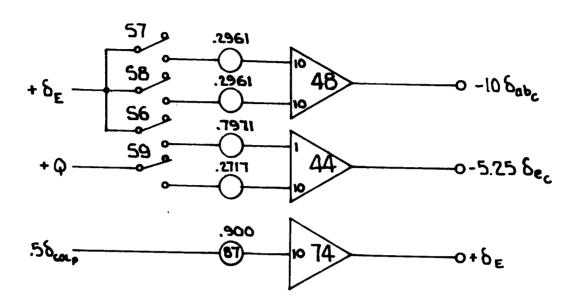
AUX. CKT. *1

CONFIG. IDIA



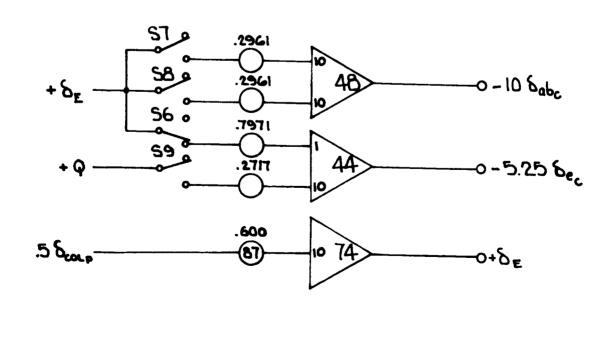
A1. 4*1 -,

CONFIG. 105*



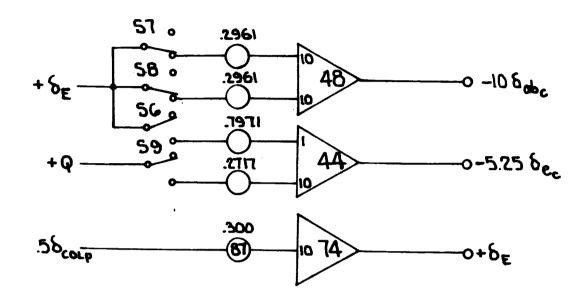
AUX. CKT. *1

CONFIG. 105A



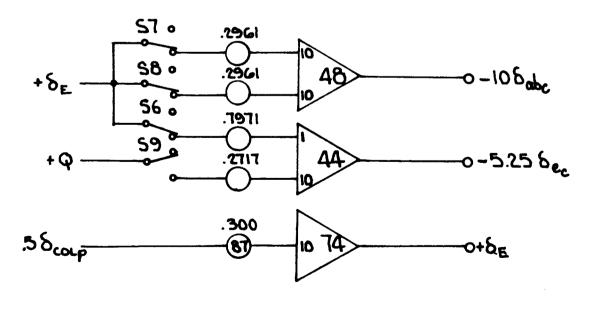
CONFIG. 151





AUX. CKT. 1

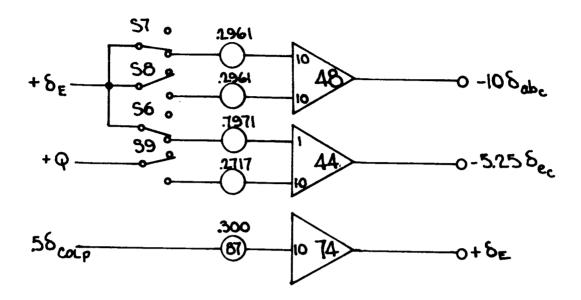
CONFIG. 151B



AD 457. C

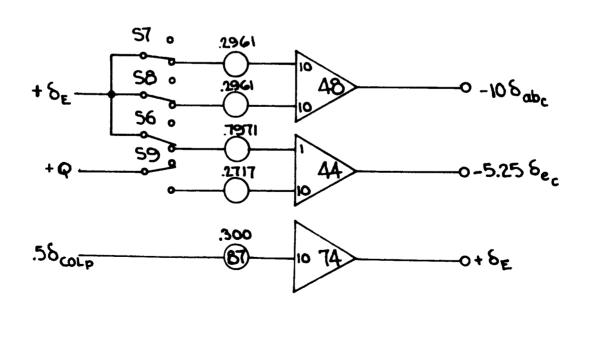
CONFIG. 151C





CONFIG. 151 D

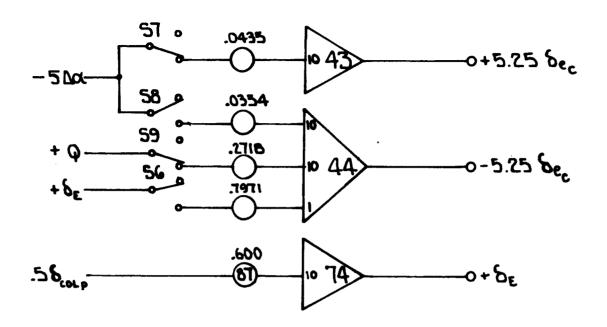
AUX. CKT. *1



AL 45726

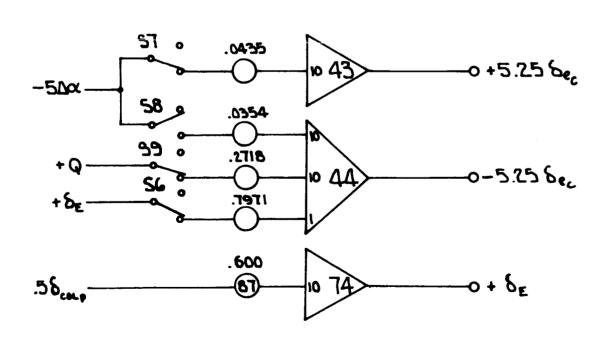
CONFIG. 158

AUX, CKT. * 2



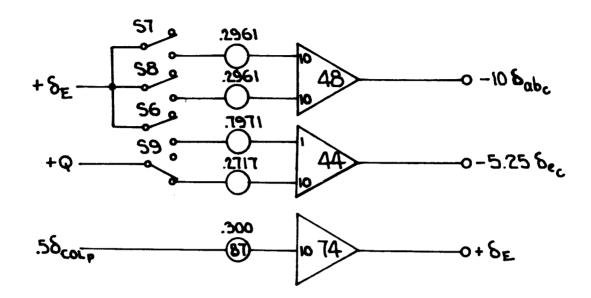
CONFIG. 158A

AUX. CKT. *2



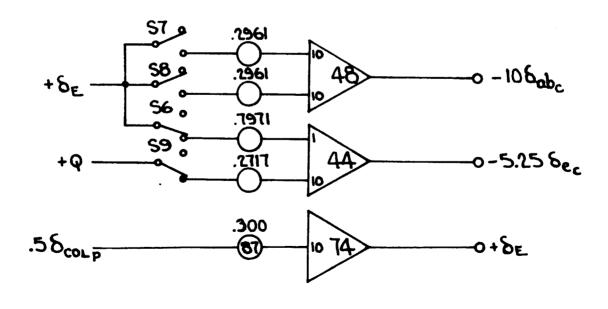
AUX. CKT. 1

CONFIG. 159



AUX. CKT. *1

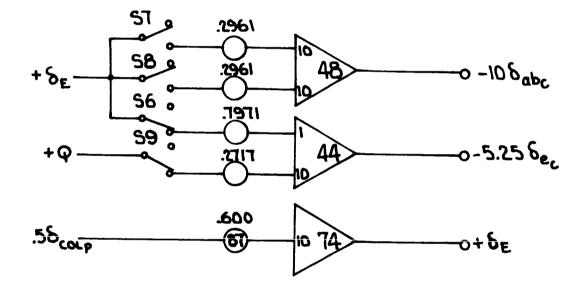
CONFIG. 159A



AL 45726

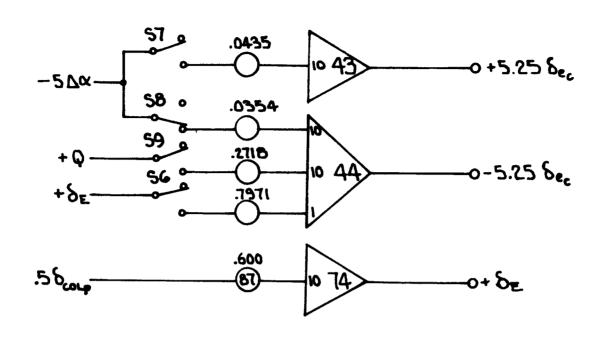
AUX.CKT.*1

CONFIG. 159B



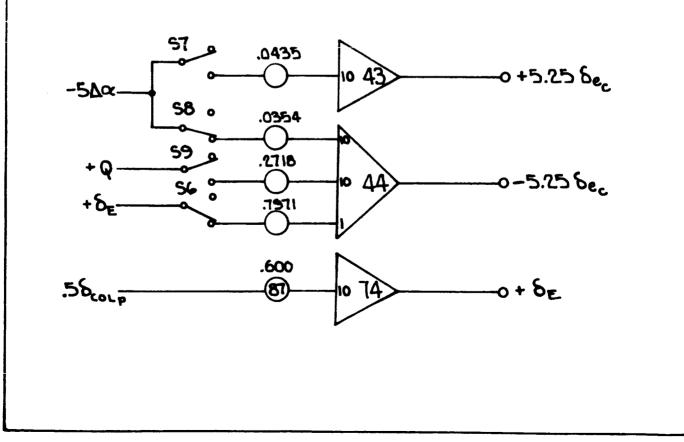
CONFIG. 161

AUX. CKT. *Z



CONFIG. IGIB

AUX. CKT. *2



APPENDIX B (Continued)

2.0 BLITZ PROGRAM RESULTS

The following section contains the BLITZ Program results that were used for the simulation and an explanation of the BLITZ sheets.

2.1 EXPLANATION OF BLITZ SHEETS

Each configuration has two BLITZ sheets. The first sheet contains the primary inputs to the program and the results of the intermediate calculations. Tables Bl and B2 give the correlation between the symbols used in the text and the symbols used on the BLITZ sheets.

Since the BLITZ Program was designed to be versatile, the BLITZ sheets contain many symbols which are either not applicable or have a numerical value of zero. These symbols have been omitted from Tables Bl and B2. The second BLITZ sheet contains additional inputs such as the scale factors of the variables and are self-explanatory (e.g., KDA is the scale factor for $\Delta \alpha$). It also contains a duplicate list of the unscaled A.L.T. Matrix gains which are used as inputs for the final set of calculations.

The last list on the second sheet contains the scaled A.L.T. Matrix gains arranged opposite the potentiometer number which is used to achieve this gain and the amplifier which it feeds (e.g., P64A44 means Potentiometer 64 feeding Amplifier 44). It should be noted that the value given is the product of the potentiometer setting and the input gain that is used for that particular input.

It should further be noted that the gains of the inputs to Amplifier 81 were calculated for an output of $2\delta\omega$, whereas the computer was actually mechanized for $\delta\omega$ so the numbers used were half those given on the BLITZ sheet.

All the numerical values are given in a base number multiplied by 10 raised to some power (e.g., 1.500000E 05 = 1.5×10^5 = 150,000. or $-7.4900000E-02 = <math>-7.49 \times 10^{-2} = -.0749$).

The first line on each sheet gives the date, reference axis (body or stability), longitudinal configuration, lateral-directional configuration and page number which is irrelevant for the purpose of this document and can be ignored.

The following examples illustrate the interpretation of this information:

- Date This is the date on which the BLITZ run was made (e.g., 1.21065E Ol = 12/10/65).
- AMESLT 1.200000E 00 is a code for the axis in which the calculation is made (e.g., 1.100000E 00 means body axis and 1.200000E 00 means stability axis).

APPENDIX B (Continued)

2.1 EXPLANATION OF BLITZ SHEETS (Continued)

- LONGAX 1.011000E 02 is a code for the longitudinal configuration number. The first three digits correspond to the number and the fourth digit is a numerical representation of a letter (e.g., 1.01100E 02 means Configuration 101A and 1.232000E 02 means Configuration 123B).
- LADIAX 1.20900QE 02 is a similar code for the lateral directional configuration number (e.g., 1.209000E 03 means Configuration 1209 and 1.207100E 03 means Configuration 1207A).

2.2 BLITZ OUTPUT SHEETS FOR VARIATIONS SIMULATED

The following BLITZ output sheets contain values for both the longitudinal and lateral-directional axes.

The sheets showing the lateral-directional variations all have the same longitudinal values (Long. 101A) and the sheets showing the longitudinal variations all have the same lateral-directional values (Lat. 1209). On every sheet the values that vary from the basic are underlined. Those longitudinal sheets that have two longitudinal variations (e.g., 101A and 105A) are valid for both the variations, the only difference between the two being the elevator to column gearing $\delta \epsilon / \delta_{\rm COL}$ which does not show up on the PLITZ output.

TABLE B1

SYMBOL	UNITS	SYMBOLS		SYMBOL	UNITS	SYMBOLS	
IN		367-80	Simulated	IN		367-80	Simulated
TEXT		Alrpiane	Airplane	TEXT		Airplane	Airplane
ng .	lb.	MG8	MGS	Ces	/RAD	CLB8	CLBS
KTRIM (Body)	Degrees	ATR8	ATRS	Ceá	/RAD/SEC		CLBDS
THRUST TRIM	lb.	THTR8	THTRS	Cep	/RAD/SEC	CLP8	CLPS
Ixx	Slugs Ft ²	IXX8	IXXS	Ceg	/RAD/SEC	CLR8	CLRS
Іуу	99	SYYI	IYYS	Clsw	/RAD	CLDW8	
Izz	91	IZZ8	IZZS	Cesw	/RAD		CLDWS
Ixz	77	IXZ8	IXZS	Cesr	/RAD	CLDR8	
q, TRIM	16/Ft ²	QTR8	QTRS	CLSR	/RAD		CLDRS
V TRIM	Ft/Sec	VTR8	VTRS	Cng	/RAD	CNB8	CNBS
S	Ft ²	s8	SS	Cnj	/RAD/SEC	CMBD8	CNBDS
b	Ft	в8	BS	Cnp	/RAD/SEC	сир8	CNPS
ō	Ft	с8	cs	Cne	/RAD/SEC	cnr8	CNRS
DTRIM		CDTR8	CDTRS	Cn Sw	/RAD	cndw8	
C _{D≪}	/RAD	CDA8	CDAS	Cnsw	/RAD		CNDWS
Cose	/RAD		CDDES	Casr	/RAD	cndr8	
LTRIM		CLTR8	CLTRS	CASR	/RAD		CNDRS
CLe	/RAD	CLA8	CLAS	CYA	/RAD	сув8	CYBS
CLá	/RAD/SEC		CLADS	Cyj	/RAD/SEC		CYBDS
Chq	/RAD/SEC	••	CLQS	CYP	/RAD/SEC	CYP8	CYPS
CLSe	/RAD	CLDE8		CYR	/RAD/SEC	CYR8	CYRS
CLSE	/RAD	••	CLDES	CYSW	/R AD	CYDW8	
CLSab	/RAD	CLDAB		CYSW	/RAD	••	CYDWS
Cmĸ	/RAD	CMA8	CMAS	Cysr	/RAD	CYDR8 .	
Cmi	/RAD/SEC	CMAD8	CMADS	CYSR	/RAD	••	CYDRS
CMAV	/FT/SEC	CMDV8					-
Cmse	/RAD	CMDE8		TABLE B			
Cmse	/RAD	••	CMDES		to Blitz Sy	mbol =	
Cmsale	/RAD	CMDAB			outs to Prog		
Cme	/RAD/SEC	смс8	CMQS	(- 14)	ACT OF LIGHT	y 40.00 /	

SYMBOL IN TEXT	UNITS	SYMBOLS 367-80 Airplane	IN BLITZ Simulated Airplane	SYMBOL IN TEXT	SYMBOLS IN BLITZ A.L.T. MATRIX GAINS (Unscaled)
SINC		SINA8	SINAS	SeSab	DE8DAB
COSK		COSA8	COSAS	δωβ	DW8B
Ixx	Slugs R ²	IXX P 8	IXXPS	δωβ	DW8BD
Izz	11	IZZ P 8	IZZPS	δωρ	DW8P
Ixz	**	IXZ P 8	IXZPS	δωκ	DW8R
9.Sc/Ivy		кріт8	KPITS	δωδω	DW 8DWS
9.Sb/		krol8	KROLS	δωδα	DW 8DRS
9. Sb/ /Ixx - Ixx				Swsr	DW8DR8
q.Sb/ /Izz-Ixz		KYAW8	KYAWS	SrB	DR8B
				δrjs	DR8BD
9.5/m		KDLS8	KDLSS	Srp	DR8P
K _{PITCH}			KPITCH	8rsw	DR8DWS
KROLL			KROLL	SrsR	DR 8DRS
KYAW			KYAW	δrsω	DR8DW8
KLIFT, DRAG			KDLS	1	
SYMBOL IN TEXT			IN BLITZ ATRIX GAINS caled)		
ΔT-80 Δx		DT8	DA	†	
ΔT-804V		DT8	D V	†	•
ΔT-80 ΔTALLIT		DT8	DTS	1	
Sabsa		DAB	DA		
δabδε		DAB	DES	1	
Sabate. T.		DAB	DTS	Ħ	
Sab AT- 80		DAB	DT8		
Sab å		DAB	AD		
Sabo		DAB	Q	#	
SeAx		DE8	DA	1	
δeż		DE8	AD	TABLE	B 2
Sea		DE8	Q	Ke	y to Blitz Symbols
δegy		DE8	DV	-14	tputs from Program)
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1.000100E	2.250000€ 2.821000€	•••	6.00000E-02 -1.071000E-01 2.700000E-01	3.000000E	-6.200000E-02 8.043000E-01 0.	1.457000E-01 -2.883000E-01 6.000000E-02	-8.702974E				-7.658657E-06	4.826592E-	1-141534E	1.342356E-	-3.736004E-04
PAGE	1 Y 8 S	CLOVE	CLOWB	(vys	CDDES CLQS CMDTS	C V P S	IXZPB				DABOTS	DEBDES	SMOSMO	DR BOWS	CCADES
1.203100E 03	2.570000E 06 1.975000E 02	0. 0. -2.720000E-01 -7.100000E-01	1.040000E-01 -1.79000E-02 0.	1.750000E 07 1.975000E 02	0. -3.959000E-01 -5.550000E-01 -2.387000E 00	1.955000E-01 9.050000E-02 -7.400000E-02	4.738313E 06		1.643488E 01 5.848990E-01	•	6.435643E-01	-4.384185E-02 -0.	-2.185805E-01	-1.610243E-01	-1.408144E-04
LADIAX	IXXB	CLOV8 CLOT8 CHAD8 CHAD8	CARB	IXXS	CDDVS CLADS CMADS CMOS	CLRS CNPS CYBDS	84221	KDL S8	KOLSS	018048	DABDES	DE8DV DE8DFS	OM ON	03 80 87	DCYR
1.011000E 02	1.819400E 04 4.640000E 01	0. 5.418000E 00 -1.100000E 00 -1.290000E-01	-1.200000E-01 -7.470000E-02 -8.380000E-01 2.110000E-01	1.147870E 05 4.640000E 01	0. 6.810000E 00 -2.070000E 00 0.	3.600006-01 3.600006-02 -9.773000E-01 2.464000E-01	2.561687E 06 1.747162E 07	3.615965E 00	3.370727E-01	3.000000E-01	-2.960689E-01	-2.161574E-01 -1.323077E-01	7.761894E-02 5.994490E-02	-6.096087E-01 -7.540621E-02	-4.099582E-03
LONGAX	E ST. LO	C0018 C4.A8 C14A8	C Y B B	THTRS	CDDTS CLAS CMAS CMDFS	CLPS CNBDS CYBS CYBS	SAXXI-	KYANS	KYAWS	018015	DABDES DABG	DE 80 DE 80 A 8	CLOWBS	DR 8P CNDR P8	DCYP
1. 200000E 00	6.500000E 00 1.600000E 05 2.010000E 01	5.440006-01 1.124200E 00 -8.080000E-01 -9.75000E-01	0. 9.090000E-02 -7.49000E-02 -2.52000E-02	2.100000E 00 9.500000E 05 2.875000E 01	1.070000E 00 1.940000E 00 0.	2.180000E-04 -1.20000E-01 -3.66000E-02	9.935728E-01	6.687655E 00	3.140891E 00 4.896551E-01	-1.646347E 02	0. 2.865860E-01	-1.599184E-01 0.	-3.047475E-02 -2.715111E-01	-1.151619E 00 1.275205E-02	-7.553669E-04
AMESLT	ATR8 1 X 28 C 8	CDA8	CLBDB CNBB CYDRB	ATRS 1XZS CS	CDAS CLTRS CLDFS CMDES	CLBDS CNBS CNDRS CYDRS	COSAB	KRDL 8	KROLS	DT8DV	DABDV	068AD DE8DT8	DWSBD	DR 80 W8	00000
1.210650E 01	1.500000E 05 4.730000E 06 1.308000E 02	9.200006-01 5.200006-01 -7.460006-04	-1.743000E-01 1.49000E-02 3.00000E-03 7.27000E-02	5.00000E 05 4.500000E 07 2.150000E 02	4.5000 COE-01 0. 4.0900 COF-01 0.	-1.955000E-01 2.290000E-03 -10.00000E-05 1.105000E-01	1.131949E-01	7.169323E 00	2.45667E-01 Z.091523E-01	-1.869572E 02	1.622218E 00 8.036862E-05	-6.841587E-01	1.390618E 00 2.521003E-02	2.9210 84E-01 5.3661 50E-01	4-648835E-03
DATE	NG8 17278 88	COTRE	CLDR8 CLDR8 CNDW8	MGS 1775	COTRS CODES CLOES CHOVS	CLORS CROWS -	SINAB	KPITB	KPITS	DT 8DA	CASDA DASDTS	DEBDA	DW 88 DW 80 R S	DR 88 DR 8DR S	DCYB

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LAT. CONFIG. # 1203A

3) 44	1.210650€ 01	AME SL.T	1.200000€ 00	OO LONGAX	1.011000E 02	02 LADIAX	1.203100E 03 PAGE	SE 2.000100E 00	
AOX	5.0000 00E 00 5.0000 00E-01	XX XX		5 X			-1.000000E 01 KDV	1 1-000000E 00	
£075	-10.000000E-03		1.000000E 01 1.000000E 00		5.250000E 00 1.000000E 00	X DM 8 X DM S	2.000000E 00 KDRB-1.000000E 00 KDRS	18 1.000000E 01	
01 6 04	-1-869572E 02	0 T 80 V	-1.646347E 02	DTBOTS	3.000000E-01	OT BDAB	0		
DASDA	1-622218E 00 8-036862E-05	04800	0. 2.865860E-01	DABDES	-2.960689E-01 -5.822206E-01	DABDER	6-435643E-01 DABDTS	.S -7.658660E-06	
DE BOTS	-6. 041587E-01 -0.	DE 8018	-1. 5991846-01	DE 8 Q DE 8 DA 8	-2-161574E-01 -1-323077E-01	DEBOY	-4-384185E-02 DEBDES	S 4.826592E-01	
DW 86 DW 80A S	1.390418E 00 2.521803E-02	DESED	-3.047479E-02 -2.715111E-01	888	7.761894E-02	DE BR	-2.185805E-01 DM8DWS	S 1.141534E 00	
DA BORS	2.921084E-01 5.364150E-01	DA 80 28	-1.151619E 00 1.275205E-02	DRBP	-6.096087E-01	DROR	-1.610243E-01 DR8DHS	S 1.342356E-02	
P64A64 P65A63 P64A63	1.679143E-01 1.134826E 00 7.183666E-01 2.301697E-01				•				
P6844 P49443 P70444	0. 6.946154E-02 2.533961E 00								
P72A46 P73A46 P76A46	1.869572E-01 1.50000E 00 8.231735E-01								
P76A46	-0. 5.731720£-01				•	,			manufacture description of the second
P80A48	1.6073726-01								
7524 763447 76546 76546	7.65660E-02 2.960689E 00 3.24436E 00 5.822206E 00					· · !			
P106A2	6.094950E-03								THE CHARLES AND THE CHARLES AN
P100A2	3-104758E-01 5-542472E-01	;						·	7
F115A1	5.042006E-02 5.042006E-02 5.430222E-02		-						
P110A3 P119A4 P120A3 P121A4	1-151619E 00 1-219217E 01 1-610243E 00 5-842168E-01	f •							
P124A3						1			

LAT. CONFIG. # 1207A

	3.		CLPS -1.200000E-01 CLRS CNBD8 -7.47000E-02 CNPS - CYSS -8.380000E-01 CYSDS CYDRS 2.110000E-01	THTRS 1.147870E 05 1XXS 1.750000E 07 1YYS 3.000000E 07 GTRS 4.640000E 01 VTRS 1.975000E 02 SS 5.500000E 03	CDDTS 0. CDDVS 0. CDDES -6.200006-02 CLAS 6.810000E 00 CLADS -3.999000E-01 CLQS 8.043000E-01 CMDTS 0. CMDS -2.387000E-01 CMDTS 0. CMQS -2.387000E 00	CLPS -2.442000E-01 CLRS 1.955000E-01 CLDMS 9.120000E-02 CNBS 3.600000E-02 CNPS 9.050000E-02 CNRS -2.883000E-01 CYBS -9.773000E-01 CYBS -7.400000E-02 CYPS 6.000000E-02 CYPS 6.000000E-02	IXXP6 2.561687E 06 122P8 4.738313E 06 1X2P8 -6.702974E 04 IXXPS 1.747162E 07 122PS 4.502838E 07 IXZPS -3.481098E 05		KYAWS 1.218708E 00 KDLSS 1.643488E 01	KYAh 3.370727E-01 KDLS 5.848990E-01	18015	ABDES -2.960689E-01 DABDE8 6.435643E-01 DABDTS -7.658657E-06	DE8G -2.161574E-01 DE8DV -4.384185E-02 DE8DES 4.826592E-01 E8DA8 -1.323077E-01 DE8DFS -0.		DM8P 7.761894E-02 DW8R -2.185805E-01 DW8DWS 7.145380E-01
1, 200000 00	6.50000E 1.600000E	5.440000E- 1.124200E- -8.080000E- -9.750000E-	0. 9.090000E-02 -7.490000E-02 -2.520000E-02	2.70000CE 00 9.50000CE 05 2.975000E 01	1.07000E 00 1.940000E 00 0.	-6.90000E-04 2.180000E-01 -1.200000E-01 -3.660000E-02	9.935728E-01 9.988900E-01	6.687655E OC	3.140891F 00	4.696551E-01	-1.646347E 02 D	0. 2.865860E-01	-1.599184E-01 0.	3-047475E-02	_
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PAGE 1778 SB	CDDE 8 CLDV8 CMDT8		CODES CLOS CMDTS	CLDMS CNR S CYP S	1 x 2 p 8			DABOTS	DE ODE S		DR BOW S DCY DW S	
1.209000E 03 2.570000E 06 1.975000E 02	0. 0. -2.720006-01 -7.1000006-01	. 790000E- . 790000E-	1.975000E_02 0. -3.959000E_01 -5.550000E_01 -2.387000E_00	1.955000E-01 9.050000E-02 -7.400000E-02	.738313E .502838E	2.809866E 01 1.643488E 01	5.848990E-01	0. 6.435643E-01	-4.384185E-02 -0.	-2.185805E-01	-1.610243E-01 -1.408144E-04	
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1.011000E 02 1.819400E 04 4.640003E 01	0. 5.418000E 00 -1.100000E 00		0. 6.810000E 30 -2.07000E 30	-2.442000E-01 3.600003E-02 -9.773000E-01 2.664003E-01	.561687E .747162E	3.615565E 00 1.218708E 00	ı.	3.000000E-01 -2.960689E-01 -5.822206E-01	-2.161574E-01 -1.323077E-01	7.761894E-02 5.994490E-02		.682373
THTR8 OTR8	CDD TB CLAB CMDAB		COUTS CHORS	CLPS CNBDS CYBS CYDRS	LHXPS	KYANB	* A A #	DTBDTS DABDES DABG	DE B D DE B DA B	CLDWRP	CNURBB	DC YDR8
1.200000E 00 1 6.500000E 00 1.600000E 05 2.010000E 01	5.440C00E-01 1.1242C0E 00 -8.080000E-01 -9.750000E-01	111	2.000000 05 2.0750006 01 1.0700006 00 1.9400006 00 0.2.2500006 00	-6.900006-04 2.1800006-01 -1.200006-01 -3.6600006-02	11	6.687655E 00 3.140891E 00	4.696551E-01	-1.646347E 02 0. 2.865860E-01	-1.599184E-C1 0.	-3.047475E-02 -2.715111E-01	-1-151619E 00 1-275205E-02	4. 397906
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1.500000E 05 4.730000E 06 1.308000E 06	1.390006-01 0. 5.200006-01 -7.460006-04	.49000E- .490000E- .000000E- .270000E-	5.000000E 05 4.500000E 07 2.150000E 02 4.500000E-01 0.	-1.955000E-01 2.29000E-03 -10.000000E-05 1.105000E-01	1.131949E-01 4.710298E-02	1.169323E 00 2.445667E-01	2.091523E-01	-1.869572E 02 1.622218E 00 8.036862E-05	-6.841587E-01 -0.	1.390618E 00 2.521003E-02	.921084E-0 .366150E-0	2.515168E-03
DATE MG8 1228 B8	CDT RB CDDAB CLDEB CMDVB	CLDR8 CNDR8 CYNB	MGS 1225 BS CDTRS CDDFS CLDES	CL BS CL DRS CNDWS -	SINAB	KP 1 18	KP11CH	DABDA DABDA DABDTB	DE BDA	DW BBB	40 64)	DCY DRS

LONG. CONFIG. # 101A \$ 105A

DATE	1.109650E 01	AMESLT	1.200000E_00	QO_LOMSAX_	1.011000E_02	LADIAX	1.209000E 03	PAGE	2.040000E DO
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	-5.000000E-01 -10.000000E-04	K DA B	. 000000E	KDEB	5.250000E_00 1.000000E_00	KDWB	2.D0D0000E D0 -1.000000E 00	KDRB	1.000000E 01
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DABDA	1.622218E 00 8.036862E-05	DABDV	0. 2.865860E-01	DABIDES DABQ	-2.960689E-01 -5.822206E-01	DABDER	6.435643E-01	DABDTS	-7.658660E-06
DEBDA	-6.841587E-01	DESOTS	-1.599184E-01	DESOAS	_2.161574E-01 -1.323077E-01	DESDY	-4.384185E-02	DEADES	4.026592E-01
DWBDAS	1.390618E 00 2.521003E-02	DWGBD	-3.047475E-02 -2.715111E-01	DES	7.761894E-02	DWGR	-2.185805E-01	DWBDWS	7.623302E-01
DRBDRS	2.921084E-01 5.366150E-01	DROOD	-1.151619E_00 1.275205E-02	DRSP	6.096087E_Q1	DRBR	-1.610243E-01	DRADKS	9-112884E-03
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LONG. CONFIG. # 106*

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	3. 346437E-01	DE BDE S	-4.384185E-02	DEB DV DEB DFS	-2.161574E-01 -1.323077E-01	DEBQ DEBINAB	-1.5991 84 E-01 0.	DE BAD DE BDT 8	-6.841587E-01 -0.	
	-7.65£657E-06	DABOTS	6.435643E-01	DABDEB	-2.960689E-01	DABDES	0. 2.865860E-01	DABDV	1.622218E 00 8.036862E-05	DABDA DABDTB
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			5.848990E-01	KDLS	3-3707276-01	KYA	4.696551E-01	KAOLL	2.091523E-01	KPSECH
			1.643488E 01	KDL SS	1.218708E 00	KYAMS	3.1408916 00	KROL S	2.45667E-01	KP17S
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	-8.702974E 04 -3.481098E 05	1 X 2 P B	4.738313E 06.4.502838E 07	12.2 P8	2.561687E 06 1.747162E 07	IXKPB	9. 935728E-01	COSA 8	- 1.131949E-01 4.710298E-02	SINAB
	9. 730000E-02 -2.883000E-01 6.000000E-02	CLDWS CNR S CYP S	1.955000E-01 9.050000E-02 -7.400000E-02	CLRS CNPS CVBDS	-2.442000E-01 3.600000E-02 -9.773000E-01 2.464000E-01	CABDS CYBS CYBS CYDRS	-6.900000E-04 2.180000E-01 -1.200000E-01 -3.660000E-02	CLBDS CNBS CNDRS CYDNS	-1.955000E-01 2.290000E-03 -10.000000E-05 1.105000E-01	CL DRS CL DRS CNOWS
	-4.200000E-02 8.043000E-01 0.	CODES CLQS CMDTS	0. -3.959000E-01 -5.55000E-01 -2.387000E 00	CDDVS CLADS CMADS CMQS	0. 6.810000E 00 -2.070000E 00	CUAS CHAS CHAS CHOFS	1.070000E 00 1.940000E 00 0.	CDAS CL TRS CLDFS CMDES	4.500000E-01 0. 4.090000E-01 0.	CDTRS CDDFS CLDES CMDVS
	3.000000E 07 5.500000E 03	1448	1.750000E 07 1.975000E 02	AXXS VTRS	1.147870E 05 4.640000E 01	OTRS	2.700000E 05 9.500000E 05 2.875000E 01	ATRS IXZS CS	5.000000E 05 4.500000E 07 2.150000E 02	HGS 1275 88
	6.000006-02 -1.0710006-01 2.7000006-01	CLDW 8 CNN 8 CVP 8	1	CYBDB	-1.20000E-01 -7.47000E-02 -8.38000E-01 2.110000E-01	CYDRS	0. 9.090000E-02 -7.490000E-02 -2.520000E-02	CLBDB	-1.743000E-01 1.490000E-02 3.000000E-03 7.270000E-02	CL DRS CL DRS CNDWS CYRS
	000	CDDE B CLDV B CMDT B	0. 0. -2.720006-01 -7.1000006-01	CLDV8 CLDT8 CMAD8 CMO8	0. 5.418000E 00 -1.100000E 00 -1.290000E-01	CCD DT8	5.440000E-01 1.124200E 00 -8.080000E-01 -9.750000E-01	CLTRB CLTRB CLDAB CLDAB	1.390000E-01 0. 5.200000E-01 -7.460000E-04	CDDAB CLOEB CHOVB
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LONG. CONFIG. # 105 *

DATE 1.10	1.109650€ 01	AME SL T	1.20000E 0	00 LONGAX	1.05MD00E 02	LADIAX	1.209000E 03	PAGE	2.040000£ 00	
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-6.84	-6.841587E-01	DE SAD DE SOTS	-1. 5991 84 E-01 0.	DESCAS	-2.161574E-01 -1.323077E-01	DEBDY	-4.384185E-02	DE BDE S	3. 346437E-01	
1.39	1.390618E 00 2.521003E-02	DW88D DW80R8	-3.047475E-02 -2.715111E-01	DESP	7.761894E-02	DM 8A	-2-185805E-01	DWBDWS	74 623302E-01	
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TRS	4.500000E-01	CDAS	1.07000E 00	CDDTS		CDDVS	.0		-6. 200000E-02
CDDFS CLDES	0. -4.090000E-01	CL DFS CADES	1.940000E 0. -1.560000E	CHAS	6.810000E 00 -2.070000E 00 0.	CHADS	-5.55000E-01 -5.55000E-01 -2.387000E 00	CMDTS	0.
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447	1,1319495-01		9.935728E	1 XXPB	.561687E		4.738313E	1 X 2 P B	-8.702974E 04
SINAS	4.710298E-02	COSAS	9.988	SAXXI	1.747162E 07	122.05		SAZXI	3.481
KP1T8	1.169323E 00	KROL 8	6.687655E 00	KYAWB	3.615565E 00	KDL S8	2.809866E 01	+	
KPITŠ	2.445667E-01	KADLS	3.140891E 00	KYAWS	1.218708E 00	KDL SS	1.643488E 01		
KPITCH	2.091523E-01	KROLL	4.696551E-01	KYAW	3.370727E-01	KDL S	5.648990E-01		
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DEBDA	-6.841587E-01 -0.	DE SOT 8	-1.599184E-01	DE 8 Q DE 8 DA 8	-2.161574E-01 -1.323077E-01	DEBDY	-4.384185E-02 -0.	DEBDES	3.346437E-01
DWBB	1.390618E 00 2.521003E-02	DWBBD	-3.047475E-02 -2.715111E-01	CLDWP8	7.761894E-02 5.994490E-02	DWBR	-2.185805E-01	DW8DWS	7.623302E-01
DROB	2.921084E-01 5.366150E-01	DRSBD	-1.151619E 00 1.275205E-02	OR 6P	-6.096087E-01 -7.540621E-02	DR 8 R	-1.610243E-01	DRBDWS	9-112884E-03
DCYB	4.648835E-03 2.515168E-03	DCYBD	-7.553669E-04	DC YP DC Y DR 8	-4.099582E-03	DCYR	-1.408144E-04	DCYDWS	-3.736004E-04

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DATE	KDA KDT &		DABDA DABDT 8	DEBDA	DWBB	DREDRS	P64A44 P65A43 P66A43	P68A44 P69A43 P70A44	P72446 P73446 P74446	P 79447	P80A48	P82A48	P85848	P106A2	P107A2	P1111A1	P112A1	P115A1	P118A3	P119A4	P121A4 P122A4	P123A3

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PAGE	1778 S8	CDDES	CLD#8	55	CDDES CLOS CMDTS	CLOWS	1X2P8 1X2P5	•	; ;	İ	DABDTS	DE BDE S	S MOS MO	DREDWS	
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1.610000E 02	1.819400E 04 4.640000E 01	0. 5.418000E 00 -1.100000E 00 -1.290000E-01	-1.200006-01 -7.470006-02 -8.380006-01 2.1100006-01	1.147670E 05 4.640000E 01	0. 6.810000E 00 -5.000000E-01	-2.442000E-01 3.600000E-02 -9.773000E-01 2.464000E-01	2.561687E 06 1.747162E 07	3.615565E 00	.218708E	3.000000E-01	-2.960689E-01	-2.161574E-01 -1.323077E-01	7.761894E-02 5.994490E-02	-6.096087E-01 -7.540621E-02	
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1.710650E 01	1.500000E 05 4.730000E 06 1.308000E 02	1.390000E-01 0. 5.20000E-01 -7.460000E-04	-1.743000E-01 1.490000E-02 3.000000E-03 7.270000E-03	5.000000E 05 4.50000E 07 2.150000E 02	4.500000E-01 0. 4.090000E-01	-1.955006-01 2.290006-03 -10.0000006-05 1.1050006-01	1.131949E-01 4.710298E-02	1.1693236 00	2.445667E-01	2.0915236-01	-1.869572E 02	1.622218E 00 8.036862E-05	-1.0209496 00	1.390618E 00 2.521003E-02	2.921094E-01 5.366150E-01	4.648835E-03
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DATE	KOA KOTO FOTS	DTADA	DA6DA DA8DT8	DESDA	DWBDRS	DR 80 RS	P64444 P65443 P66443 P61443 P69444 P69443	972A46 973A46 974A46 976A46	90000000000000000000000000000000000000	P106A2 P107A2 P109A2 P111A1 P112A1	P118A3 P119A4 P120A3 P121A4 P122A4
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APPENDIX C

AIRPLANE ELECTRO-HYDRAULIC POWER

CONTROL UNITS

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APPENDIX C - AIRPLANE ELECTRO-HYDRAULIC POWER CONTROL UNITS

The 367-80 airplane is equipped with electro-hydraulic power control units on the following controls: Left hand elevator, right hand elevator, spoilers, rudder, aileron, lateral control system (spoiler drive PCU).

In addition, the thrust reversers are controlled by an electric servo system which drives the reverser levers which in turn control the clam shell hydraulic actuators.

During the -80 variable stability programs, the electro-hydraulic actuators are utilized to accept signals from the airborne computer and drive the -80 control surfaces to perform the dynamics of the simulated airplane. For this we have 5 degree of freedom control, the pitching equation by elevator, the roll equation by wheel (lateral control), the drag equation by thrust reverser modulation, the yawing moment equation by rudder, and the lift equation by spoilers. For each of the aforementioned systems, this appendix contains a block diagram, transient response, frequency response, the linearized transfer functions, surface rate limits, and displacement limits. Also, the hysteresis of the lateral control system is included.

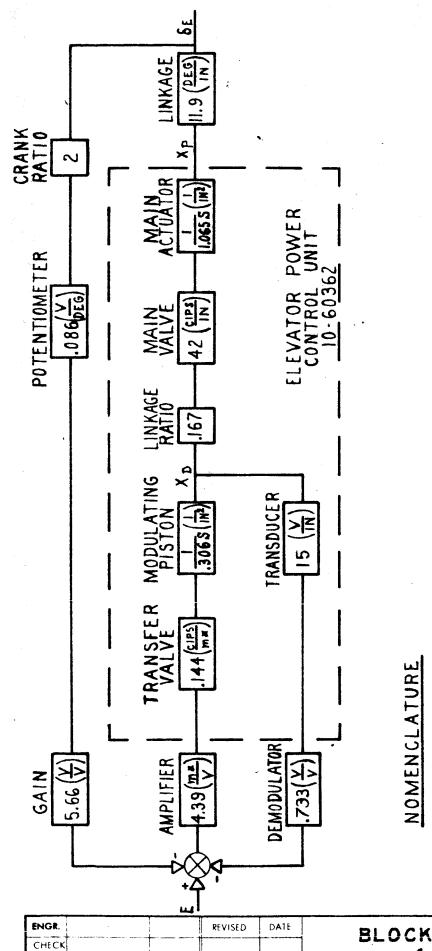
In summarizing, the 367-80 is equipped with the electro-hydraulic actuators on each controlled axes except thrust reversers, the dynamics of which are very good and the frequency response entirely sufficient for use in a variable stability control system.



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NOMENCLATURE

INPUT VOLTAGE, VOLTS

MODULATING ACTUATOR DISPLACEMENT, INCHES

DIAGRAM

THE BOEING COMPANY

RENTON. WASHINGTON

OPILOT MODE)

MAIN ACTUATOR DISPLACEMENT, INCHES

ELEVATOR DISPLACEMENT. DEGREES

- LAPLACE OPERATOR

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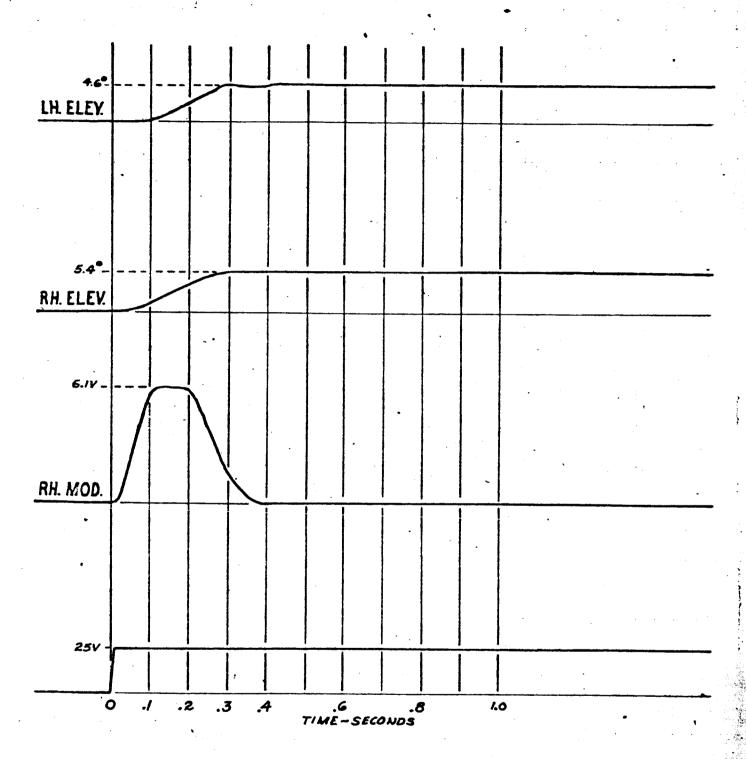
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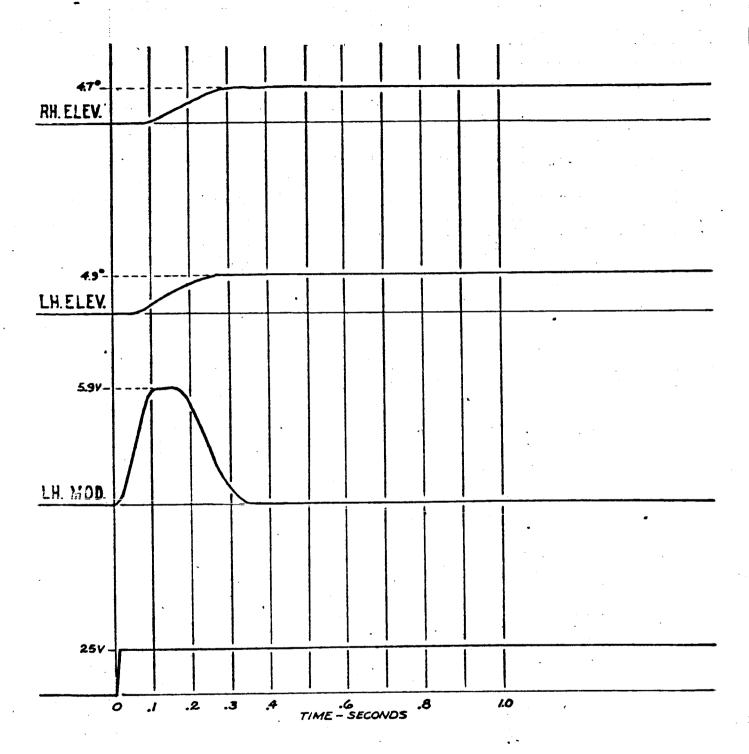
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CHECK		1				FIG. 2
APR					ELEVATOR TRANSIENT RESPONSE	
APR.					(ELECTRICAL MODE)	
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CALC	D. E. G.	4-13-65	REVISED	DATE	LEFTHAND MASTER	FIG. 3
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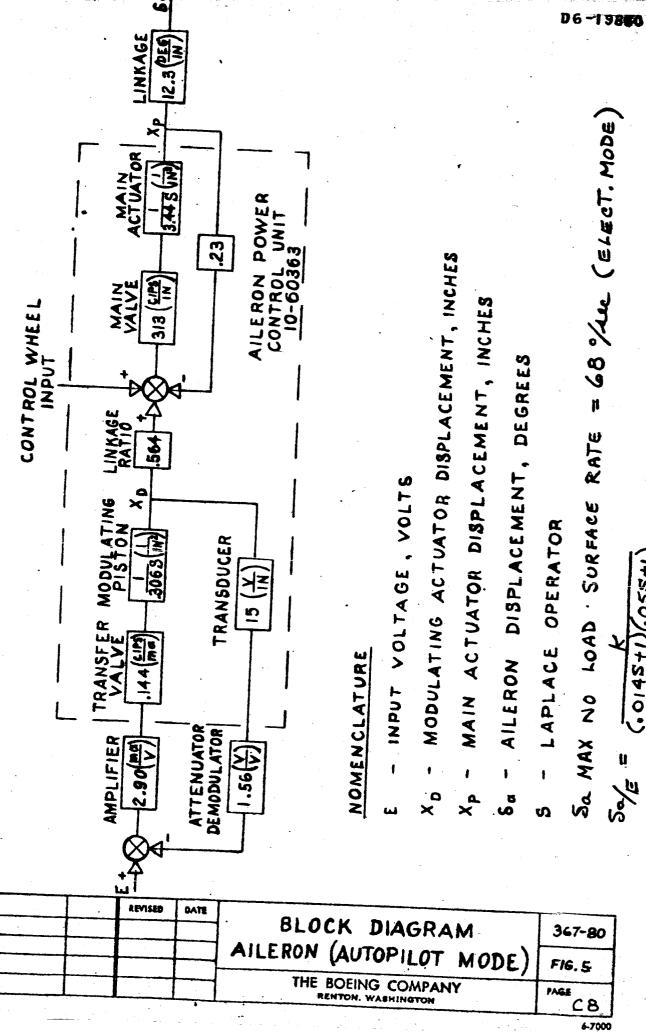


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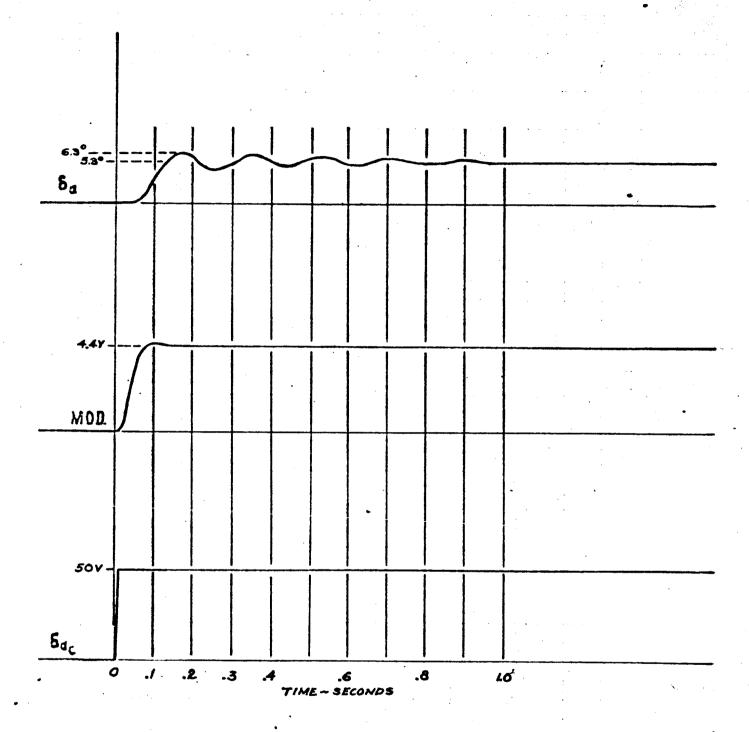
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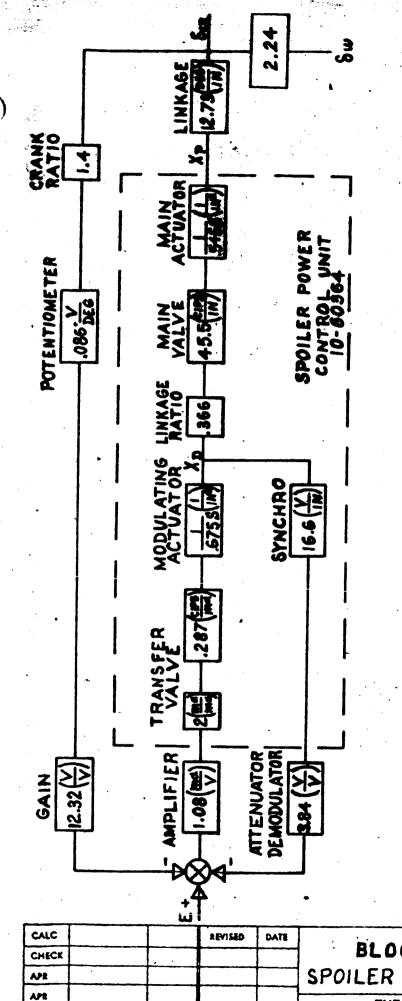


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APR					(ELECTRICAL MODE)	
APR						PAGE
					THE BOEING COMPANY	(13. C9)

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AILERON -.02 .02 CALC REVISED 367-80 AILERON PCU HYSTERESIS CHECK FIG. 8 PAGE THE BOEING COMPANY TD 461 C-R4



NOMENCLATURE

E - INPUT VOLTAGE, VOLTS

MODULATING ACTUATOR DISPLACEMENT, INCHES

BOEING COMPANY

RENTON, WASHINGTON

SPOILER ACTUATOR CRANK DISPLACEMENT

MAIN ACTUATOR DISPLACEMENT, INCHES

S - LAPLACE OPERATOR 6w - SAFETY PILOTS WHEEL POSITION, DEGREES

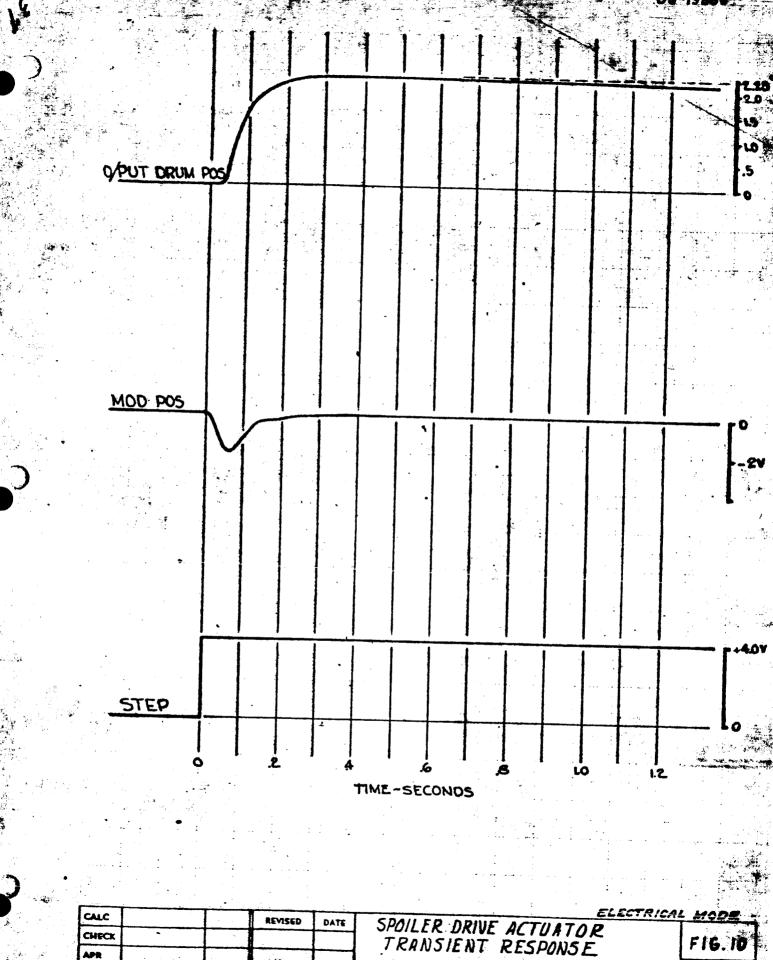
(ELECT, MODE) = 180 % 160 RATE **S**€ M A X

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F16. 9

C12

SW MAX = +63° (ELECT. MODE)

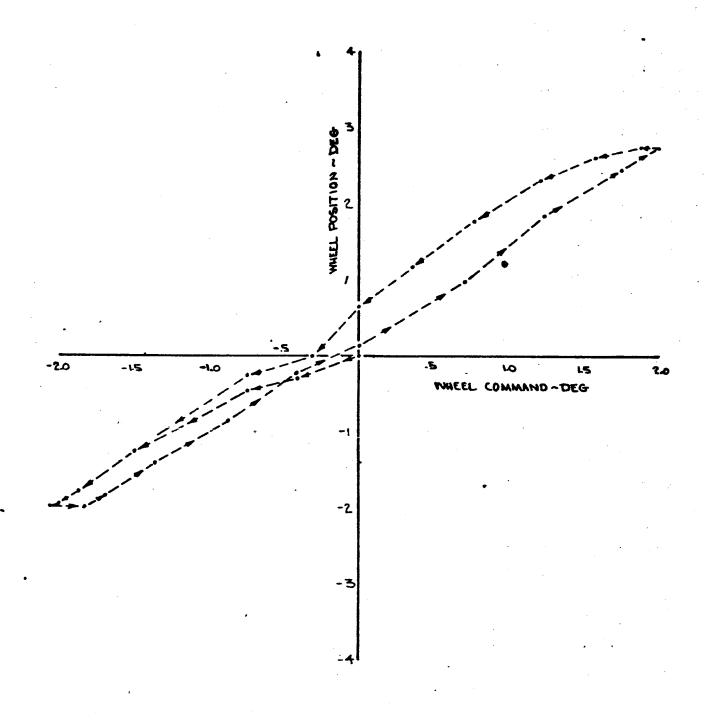


TRANSIENT RESPONSE

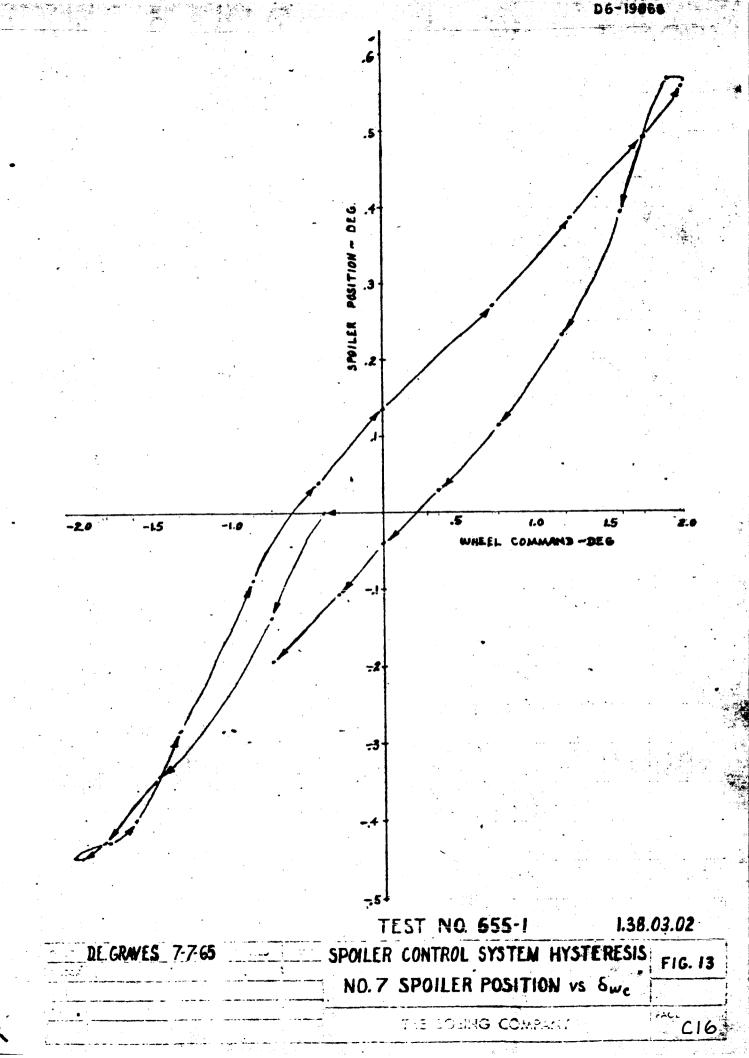
TEST NO 655-1

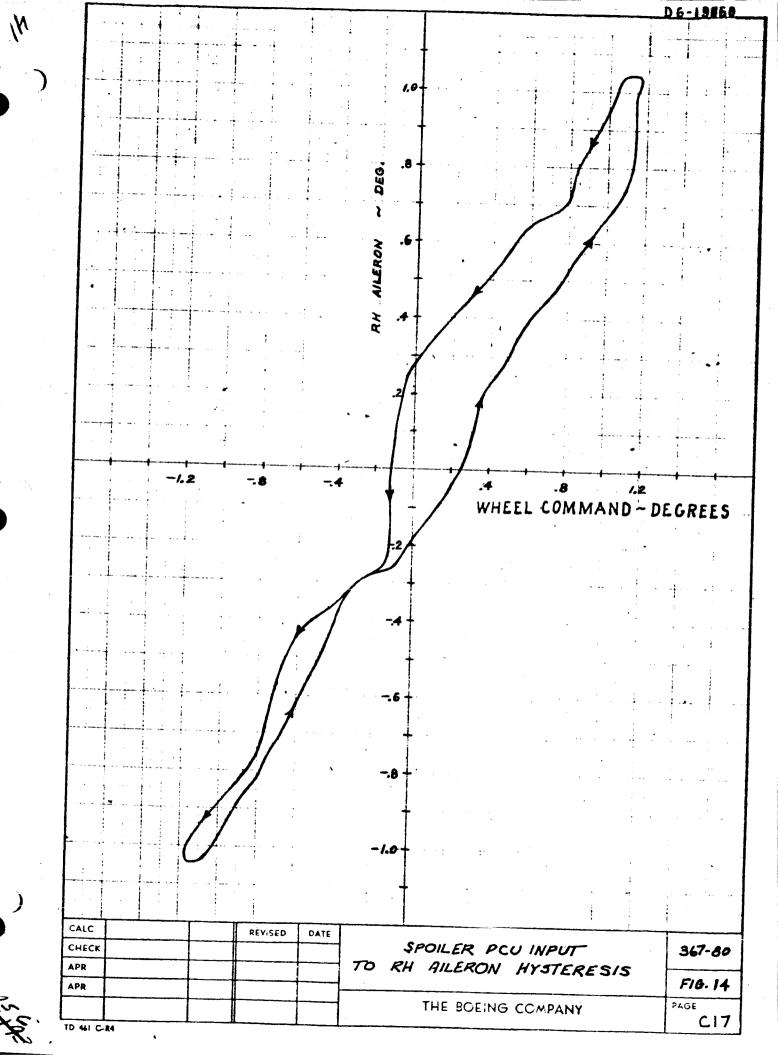
THE BOEING COMPANY

PAGE C13



			ELECTRICAL MODI	e.
CALC	REVISED	DATE	SPOILER CONTROL SYSTEM HYSTERES	ς
CHECK				FIG. 12
APR			TEST NA (EE)	
APR			TEST NO 655-1 1.38.03.02	
			THE BOEING COMPANY	PAGE C15





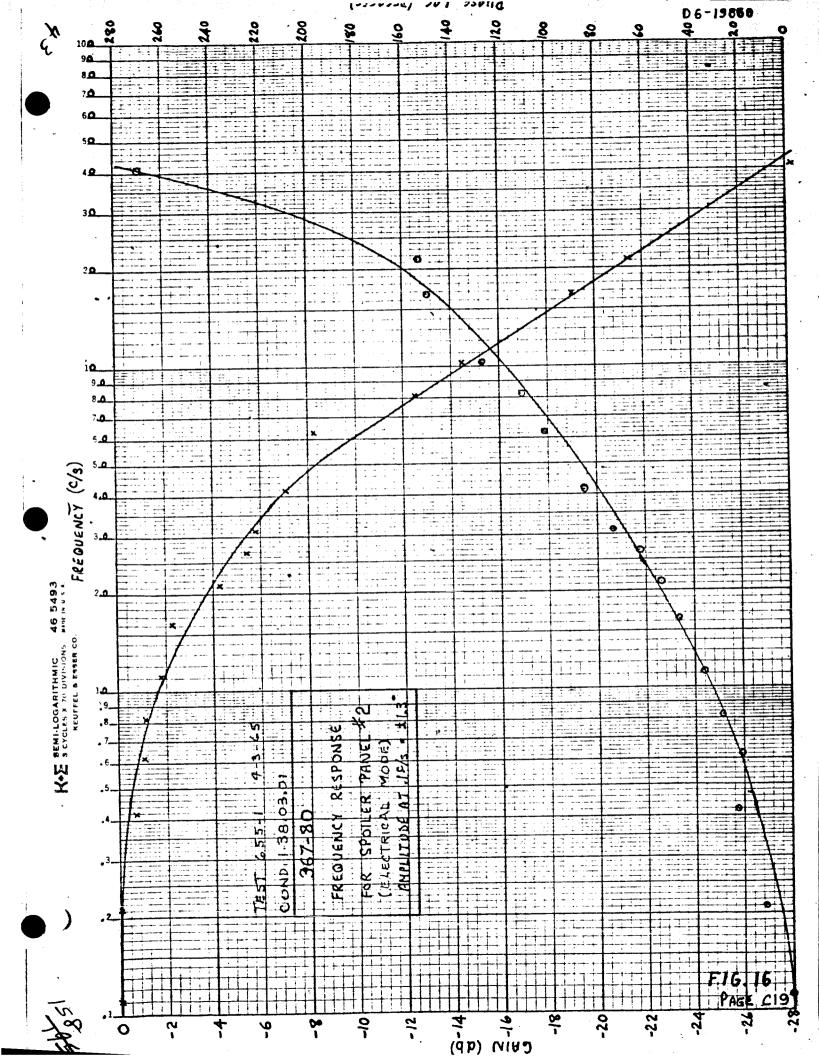
SPOILER STEP

MAX. NO LOAD RATE = 50°/SEC (ELECTRICAL MODE)

 $8sp/s\approx \frac{K}{(.06S+1)}$

LIMIT ±10°

			TEST NO. 655-1	COND FAR.03.03
CALC	REVISED	DATE	SPOILER ACTUATOR G	F1G.15
CHECK			TRANSIENT RESPONSE	
APR			(ELECTRICAL MODE)	
APR			THE BOEING COMPANY	PAGE
-		1	THE BOEING COMPANY	C10



RUDDER MOD. 50V $\delta_{\boldsymbol{r_{\!\boldsymbol{c}}}}$.2 .6 TIME ~ SECONOS 40

MAX NO LOAD RATE = 33 % sec

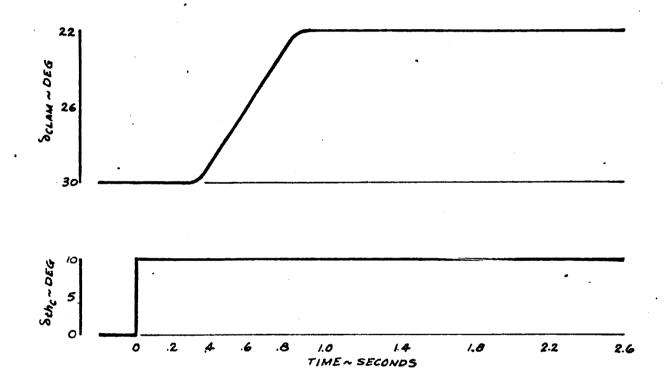
$$Sr/E_{IN} = \frac{K}{(.065+1)(.0285+1)}$$

LIMIT ±10° ELECT.

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CALC	D.E.G.	4.13.65	REVISED	DATE	DINDER TRANSPORT BECOME	
CHECK					RUDDER TRANSIENT RESPONSE	F1G. 17
APR					(ELECTRICAL MODE)	
APR				1 }		
			•		THE BOEING COMPANY	C20



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MAX CLAM SHELL RATE = 14 % ALC $\frac{\text{SCLAM}}{\text{EIN}} \approx \frac{K}{(.045+1)(.195+1)}$

CALC	PEVISED (ATE	THRUST MODULATION SYSTEM	516.10
CHECK		ELECTRICAL MODE	FIG. 18
APR		TRANSIENT RESPONSE	
APR			FAGE
		THE BOEING COMPANY	C21,



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	ACTIVE SHEET RECORD											
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